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1883.

PROCEEDINGS

OF THE

UNITED STATES

NAVAL INSTITUTE.

VOLUME IX.

PUBLISHED QUARTERLY BY THE INSTITUTE.

ANNAPOLIS, MD.

PRESS OF ISAAC FRIEDENWALD,
BALTIMORE, MD.

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Wilson, H. B.	Naval Cadet
Wilson, J. C.	Lieutenant
Wilson, T. D.	Chief-Constructor
Windsor, W. A.	P. Asst. Engineer
Winn, J. K.	Lieut.-Commander
Winslow, F.	Lieutenant
Winterhalter, A. G.	Ensign
Wise, F. M.	Lieutenant
Wood, E. P.	Lieutenant
Wood, S. S.	Naval Cadet
Wood, W. M.	Lieutenant
Woolfersberger, W. H.	Naval Cadet
Woolverton, T.	Surgeon
Worden, J. L.	Rear-Admiral
Worthington, W. F.	Asst. Engineer
Wright, M. F.	Lieutenant
Wright, R. K.	Ensign
Yates, A. R.	Commander
Yates, I. I.	Lieutenant
Young, J. M. T.,	1st Lieut. U.S.M.C.
Zane, A. V.	P. Asst. Engineer

LIFE MEMBERS—16.

Brown, A. D., Commander, Prize Essayist, 1879
Belknap, C., Lieutenant, Prize Essayist, 1880
Very, E. W., Lieutenant, Prize Essayist, 1881
Kelly, J. D. J., Lieutenant, Prize Essayist, 1882
Calkins, C. G., Lieutenant, Prize Essayist, 1883

Allen, R. W.	Paymaster
Barker, A. S.	Commander
Forbes, R. B., Hon.	Milton, Mass.
Gorringe, H. H., Esq.	New York
Hanford, F.	Lieutenant
Mason, T. B. M.	Lieutenant
Moore, J. H.	Lieutenant
Phœnix, Lloyd, Esq.	New York
Thomas, C. M.	Lieut.-Commander
Ward, Aaron	Lieutenant
Watrous, Chas., Esq.	New York

HONORARY MEMBERS—9.

Arranged in order of Election.

Hon. W. E. Chandler (ex-officio).
Chief-Justice C. P. Daly.
President C. W. Eliot, LL. D.
Captain J. Ericsson.
General U. S. Grant.
Hon. G. V. Fox.
Professor J. E. Hilgard.
John D. Jones, Esq.
Lieutenant Alfred Collet.

ASSOCIATE MEMBERS—20.

Acland, W. A. D.	Commander R. N.
Batten, A. W. C.	Lieutenant R. N.
Brenton, R. O. B. C.	Lieut. R. N.
Boutelle, C. O.,	Capt. Assistant C. S.
Brooke, J. M.	Prof. Lexington, Va.
Chase, Constantine,	1st Lieut. U.S.A
Chase, Leslie, Esq.	New York
Forster, E. J., M. D.	Boston, Mass.
Hoffman, J. W., Esq.	Philadelphia
Hunt, W. P., Esq.	Boston, Mass.
Lyon, Henry, M. D.	Boston, Mass.
Mensing, A.	Comd'r Imp. G. Navy
Miller, H. W., Esq.	Morristown, N. J.
Myers, T. B., Esq.	New York
Nordhoff, C., Esq.	Alpine, N. J.
Ropes, J. C., Esq.	Boston, Mass.
Russell, A. H.	1st Lieut. U. S. A.
Sargent, C. S.	Prof. Harvard Univ.
Simpson, J. M.,	Capt. Chilian Navy
Wilson, A. E.,	Lieut. Chilian Navy

CORRESPONDING SOCIETIES.

United States.

American Academy of Arts and Sciences, Boston, Mass.
American Geographical Society, New York City.
American Institute of Mining Engineers, Easton, Pa.
American Metrological Society, Columbia School of Mines, New York City.
American Philosophical Society, Philadelphia, Pa.
American Society of Civil Engineers, New York City.
American Society of Mechanical Engineers, New York City.
Franklin Institute, Philadelphia, Pa.
Military Service Institution of the U. S., Governor's Island, N. Y.
New York Genealogical and Biographical Society, New York City.
The School of Mines Quarterly, New York City.
The Ohio Mechanics Institute, Cincinnati, O.

Foreign.

Association Parisienne des Propriétaires d'Appareils à Vapeur, Paris.
Giornale d'Artiglieria e Genio, Rome.
Hydrographisches Amt der Kaiserlichen Marine, Berlin.
Institute of Mining and Mechanical Engineers, Newcastle-upon-Tyne.
Institution of Mechanical Engineers, London.
Mittheilungen a. d. Gebiete d. Seewesens, Pola.
Réunion des Officiers de Terre et de Mer, Paris.
Rivista Marittima, Rome.
Royal Artillery Institution, Woolwich.
Royal United Service Institution, London.
Société des Ingénieurs Civils, Paris.

NAVAL INSTITUTE PRIZE ESSAYS, 1879–1883.

1879.

Subject: "NAVAL EDUCATION.—I. OFFICERS. II. MEN."

Judges of Award:—CHARLES W. ELIOT, President of Harvard University; DANIEL AMMEN, Rear-Admiral, U. S. N.; WM. H. SHOCK, Engineer-in-chief, U. S. N.

Winner of the Prize:—Lieutenant-Commander ALLAN D. BROWN, U. S. N. *Motto of Essay:*—"Qui non proficit."

First Honorable Mention:—Lieutenant-Commander CASPAR F. GOODRICH, U. S. N. *Motto of Essay:*—"Esse quam videri."

Second Honorable Mention:—Commander ALFRED T. MAHAN, U. S. N. *Motto of Essay:*—"Essayons."

Number of Essays presented for competition, ten.

1880.

Subject:—"THE NAVAL POLICY OF THE UNITED STATES."

Judges of Award:—Hon. WM. M. EVARTS, Secretary of State; Hon. R. W. THOMPSON, Secretary of the Navy; Hon. J. R. MCPHERSON, U. S. Senator.

Winner of the Prize:—Lieutenant CHARLES BELKNAP, U. S. N. *Motto of Essay:*—"Sat cito, si sat bene."

Number of Essays presented for competition, eight.

1881.

Subject:—"THE TYPE OF (I) ARMORED VESSEL, (II) CRUISER, BEST SUITED TO THE PRESENT NEEDS OF THE UNITED STATES."

Judges of Award:—Commodore W. N. JEFFERS, U. S. N.; Chief Engineer J. W. KING, U. S. N.; Chief Constructor JOHN LENTHALL, U. S. N.

Winner of the Prize by decision of two of the Judges:—Lieutenant EDWARD W. VERY, U. S. N. *Motto of Essay:*—"*Aut Cæsar, aut nullus.*"

Recommended for the Prize by one of the Judges:—Lieutenant SEATON SCHROEDER, U. S. N. *Motto of Essay:*—"In via virtute via nulla."

Number of Essays presented for competition, four.

1882.

Subject:—"OUR MERCHANT MARINE; THE CAUSES OF ITS DECLINE AND THE MEANS TO BE TAKEN FOR ITS REVIVAL."

Judges of Award:—Hon. HAMILTON FISH, Ex-Secretary of State; JOHN D. JONES, President Atlantic Mutual Insurance Company, New York; A. A. LOWE, Ex-President New York Chamber of Commerce.

Winner of the Prize:—Lieutenant JAMES D. J. KELLY, U. S. N. *Motto of Essay*:—"Nil clarius aquis."

First Honorable Mention:—Master CARLOS G. CALKINS, U. S. N. *Motto of Essay*: "Mais il faut cultiver notre jardin."

Second Honorable Mention:—Lieutenant-Commander F. E. CHADWICK, U. S. N. *Motto of Essay*:—"Spero meliora."

Third Honorable Mention:—Lieutenant RICHARD WAINWRIGHT, U. S. N. *Motto of Essay*:—"Causa latet: vis est notissima."

Essay printed by request of John D. Jones, Esq. Ensign W. G. DAVID, U. S. N. *Motto of Essay*:—"Tempori parendum."

Number of Essays presented for competition, eleven.

1883.

Subject:—"HOW MAY THE SPHERE OF USEFULNESS OF NAVAL OFFICERS BE EXTENDED IN TIME OF PEACE WITH ADVANTAGE TO THE COUNTRY AND THE NAVAL SERVICE."

Judges of Award:—Hon. ALEXANDER H. RICE, Judge JOSIAH G. ABBOTT, Rear-Admiral GEORGE H. PREBLE, U. S. N.

Winner of the Prize:—Lieutenant CARLOS G. CALKINS, U. S. N. *Motto of Essay*:—"Pour encourager les autres."

First Honorable Mention:—Commander N. H. FARQUHAR, U. S. N. *Motto of Essay*:—"Semper paratus."

Second Honorable Mention:—Captain A. P. COOKE, U. S. N. *Motto of Essay*:—"Cuilibet in arte suâ credendum est."

Number of Essays presented for competition, four.

NECROLOGY.

Medical Inspector Benjamin Franklin Gibbs. Born in New Jersey, August 18, 1836. November 12, 1858, appointed Assistant Surgeon. December 4, 1858, to the Memphis. May 23, 1859, detached and placed on waiting orders. May 25, 1859, to the John Adams. January 20, 1862, detached and granted leave. June 2, 1862, Naval Rendezvous, Philadelphia. June 23, 1862, detached and placed on waiting orders. June 30, 1862, commissioned as Surgeon from the 22d May, 1862. September 8, 1862, to the West Gulf blockading squadron. December, 1862, Naval Hospital, Pensacola, Fla. October 28, 1863, detached and to the Ossipee. May 6, 1865, detached and placed on waiting orders. August 23, 1865, to the Sabine. May 4, 1866, detached and placed on waiting orders. June 7, 1866, to the Sabine. October 11, 1866, detached and to the Ossipee. June 28, 1869, detached and placed on waiting orders. July 12, 1869, to duty connected with ironclads at New Orleans. January 22, 1873, detached and to the Richmond. December 11, 1873, detached and placed on waiting orders. February 26, 1874, to special duty at New Orleans. June 4, 1874, detached and to the Navy Yard, Norfolk. October 10, 1874, detached and to the Richmond as Fleet Surgeon of Pacific Station. March 17, 1876, promoted to Medical Inspector. September 3, 1877, detached and placed on waiting orders. September 25, 1877, member of the Naval Retiring and Examining Boards. August 15, 1881, detached and to the Lancaster as Fleet Surgeon of the European Station. September 9, 1882, died at Trieste, Austria. Sea service, thirteen years, 11 months. Shore duty, eight years, four months. Total service, twenty-three years, eleven months.

Naval Constructor John Lenthall. Born, Washington, D. C., September 10, 1807. At the age of 15 was apprenticed to Naval Constructor Humphreys, Navy Yard, Philadelphia, and completed his apprenticeship at the Navy Yard, Washington. Passed

three years in Europe, spending the greater part of this time inspecting the dockyards of England and France. Appointed Naval Constructor February 8, 1838, and ordered to the Navy Yard, Philadelphia, where he remained on duty till 1849, when he relieved Mr. Francis Grice as Chief Constructor. November 18, 1853, appointed Chief of the Bureau of Construction and Repair. July 28, 1866, re-appointed. August 18, 1866, commissioned Naval Constructor to take rank from July 25, 1866. September 16, 1869, placed on the retired list. January 24, 1871, ordered as General Inspector of Ships. January 28, 1871, relieved from duty as Chief of the Bureau of Construction and Repair. June 30, 1873, relieved from special duty and placed on waiting orders. July, 1881, appointed a member of the Naval Advisory Board, of which Rear-Admiral John Rodgers was President. April 11, 1882, died at Washington, D. C.

Rear-Admiral John Rodgers. Born in Maryland, August 8, 1812. Appointed Midshipman April 18, 1828. June 10, 1829, to the Constellation. November 25, 1830, warranted Midshipman from April 18, 1828. December 16, 1832, detached and placed on waiting orders. March 26, 1833, permitted to attend Naval School at Norfolk. June 14, 1834, promoted to Passed Midshipman. March 31, 1836, to the Coast Survey schooner Jersey. September 29, 1836, detached and to the brig Dolphin. May 23, 1839, detached and granted leave. November 9, 1839, to command the schooner Wave. January 28, 1840, promoted to Lieutenant. Transferred to the command of the schooner Jefferson. July 30, 1842, detached and granted leave. November 22, 1842, to the brig Boxer. January 9, 1844, detached and granted leave. May 7, 1844, to report to Lieutenant W. H. Hunter, U. S. N., for duty at Pittsburg, Pa. January 22, 1846, detached and placed on waiting orders. May 5, 1846, to the United States. February 22, 1849, detached and granted three months' leave. April 27, 1849, to Coast Survey duty. October 12, 1852, detached and to duty connected with the North Pacific Exploring and Surveying Expedition, consisting of the Vincennes, John Hancock, Porpoise, and Fenimore Cooper. Commanded the John Hancock. August, 1854, transferred to command of Vincennes. October 8, 1855, commissioned as Commander from September 14, 1855. July 17, 1856, detached from the command of the Vincennes. August 30, 1856, to special duty at Washington. May 24, 1858, to command the Water Witch. July 17, 1858, detached and to special

duty at Washington. May 16, 1861, to special duty at Cincinnati, with General George B. McClellan, U. S. A. September 23, 1861, detached and to return to Washington and report at Department. October 17, 1861, to command the Flag. March 15, 1862, detached and to special duty at Washington. April 21, 1862, detached and to command the Galena. July 16, 1862, promoted to Captain. November 8, 1862, detached from the command of the Galena and to command the Weehawken. June 18, 1863, detached and to return north and assume command of steamer Fort Jackson. July 17, 1863, orders revoked, and to the command of the Canonicus. September 11, 1863, detached (sick) and placed on waiting orders. November 3, 1863, to command the Dictator. March 2, 1864, commissioned as Commodore from June 17, 1863. September 2, 1865, to command the Vanderbilt. September 14, 1865, detached and to command a special squadron. June 28, 1866, detached, and to command the Navy Yard, Boston, December 15, 1866. December 15, 1869, detached and placed on waiting orders. December 31, 1869, promoted to Rear-Admiral. February 5, 1870, to command the Asiatic Station. May 15, 1872, detached, to return home and placed on waiting orders. July 26, 1872, President of the Naval Examining and Retiring Board. June 15, 1873, detached, and to command the Navy Yard, Mare Island, June 30. April 17, 1877, detached and to duty as Superintendent of the Naval Observatory. May 1, 1878, ordered, in addition to duties as Superintendent of the Naval Observatory, as member (elected Chairman) of the Light-house Board, and on June 29, 1881, as President of the Naval Advisory Board. May 5, 1882, died at Washington, D. C. Sea service, twenty-six years, three months. Shore duty, twenty-one years, three months. Total service, fifty-four years, one month.

Commander Edward Terry. Born in Connecticut, January 24, 1839. Appointed Midshipman, September 21, 1853. June 12, 1857, detached from the Naval Academy and to the Minnesota. June 13, 1857, warranted as Midshipman from June 10, 1857. June 22, 1857, previous order revoked and placed on waiting orders. June 24, 1857, to the Germantown. April 14, 1860, detached and granted leave. July 3, 1860, warranted as Passed Midshipman from June 25, 1860. August 28, 1860, to the Richmond. October 24, 1860, warranted as Master. April 3, 1861, promoted to Lieutenant. April 18, 1863, commissioned as Lieutenant-Commander from January 4,

1863. February 10, 1865, detached from the Richmond and placed on waiting orders. August 10, 1865, to the Powhatan. November 16, 1867, detached and placed on waiting orders. December 23, 1867, Naval Academy. July 12, 1870, detached and to command the Saco. October 31, 1871, promoted to Commander. June 9, 1873, detached from command of the Saco and placed on waiting orders. September 1, 1873, Naval Academy. June 30, 1878, detached, and as Fleet Captain of the Pacific Station, July 9. June 7, 1880, detached and granted leave for one year. June 1, 1882, died at Manitou, Colorado. Sea service, sixteen years, two months. Shore duty, nine years, four months. Total service, twenty-eight years, eight months.

Rear-Admiral Robert Harris Wyman. Born in New Hampshire, July 18, 1822. Appointed Midshipman, March 11, 1837. To the Independence, March, 1837. June, 1840, detached and granted three months' leave. September, 1840, to the West India squadron; served on board the Levant, Concord, and Potomac. August, 1842, detached from the Potomac and granted three months' leave. 1842–1843, Naval School, Philadelphia. June, 1843, to the Onkahye. June 29, 1843, promoted to Passed Midshipman. August, 1843, detached from the Onkahye and ordered to the Perry as Acting Master. Transferred to the Brandywine. September, 1845, detached and granted three months' leave. Receiving-ship at Boston, until March, 1846; detached and to the Princeton as Acting Master. Transferred to the Porpoise and served on these two vessels during the Mexican War. Present at siege of Vera Cruz. June, 1847, detached from the Porpoise. July, 1847, Naval Rendezvous, Boston. September, 1847, detached and to the Albany as Acting Master. January, 1848, detached (sick), placed on waiting orders. February, 1848, Naval Observatory. June, 1848, detached and to the Receiving Ship, Boston, as Acting Master. June, 1850, detached and placed on waiting orders. July, 1850, promoted to Lieutenant. September, 1850, to the St. Mary's. December, 1852, detached and granted leave. February, 1853, Naval Observatory. October, 1854, detached and to the practice-ship Preble. October, 1856, detached and placed on waiting orders. November, 1856, to the Wabash for passage from New York to Panama for duty on the St. Mary's. Transferred to the Independence. August, 1857, rejoined the St. Mary's. January, 1859, detached and to the Navy Yard, New York. April, 1859,

detached and to the practice-ship Plymouth. August, 1860, detached and to the Richmond. July, 1861, detached and to command the Yankee. October, 1861, detached and to command the Pawnee, where he remained about one month, then detached (sick) and placed on waiting orders. Present at taking of Port Royal. December, 1861, to command the Potomac Flotilla. June, 1862, detached and to command the Sonoma, serving on the James River. July, 1862, promoted to Commander. September, 1862, detached from the Sonoma and to command the Wachusett. November, 1862, detached and to special duty at Washington, D. C. March, 1863, detached and to command the Santiago de Cuba, at Havana. August, 1863, detached and to report at the Department. May 10, 1865, to command the Colorado. Transferred to the command of the Ticonderoga. April, 1869, detached and placed on waiting orders. July, 1866, promoted to Captain. October, 1869, to the Hydrographic Office. October, 1870, in charge of Hydrographic Office. July, 1872, promoted to Commodore. April, 1878, promoted to Rear-Admiral. January, 1879, detached from the Hydrographic Office and ordered to command the North Atlantic Station. May, 1882, detached from command of the North Atlantic Station and placed on waiting orders. May 25, 1882, Member of Light-house Board; elected Chairman of the Board. December 2, 1882, died at Washington, D. C. Sea service, twenty-three years, five months. Shore duty, nineteen years, eleven months. Total service, forty-five years, nine months.

ANNUAL REPORT OF THE SECRETARY.

Mr. President, and Members of the Naval Institute:

I have the honor to submit the following report concerning the affairs of the Naval Institute for the year 1882.

There has been a most gratifying increase in the membership, as will be seen from the following statement:

	Jan. 1, 1882.	Jan. 1, 1883.	Increase.	Decrease.
Members,	474	547	73	...
Life members,	4	15	11	...
Honorary members,	6	9	3	...
Associate members,	22	20	...	2
	506	591	87	2

As a matter of interest I submit a table showing the growth of the Institute since January, 1879:

	1879.	1880.	1881.	1882.	1883.
Members,	253	368	454	474	547
Life members,	...	2	2	4	15
Honorary members,	5	5	6	6	9
Associate members,	9	7	19	22	20
Total,	267	382	481	506	591

There is no record of membership previous to 1879, and it is to be regretted that the comparison cannot be further extended.

In the Secretary's last report, Lieut. Chas. Belknap, my predecessor, mentioned the fact that the Secretary of the Navy had subscribed for 50 copies of each number of the Proceedings, permitting 25 copies to be sent to the exchanges of the Institute. I am happy to state that this subscription has been continued, and that it has been supplemented by a subscription from the Bureau of Navigation for 50 copies.

The increased issue of the Proceedings at the present time over

January, 1882, is 144 copies, as will be seen from the following statement:

	Jan. 1882.	Jan. 1883.
Members,	474	547
Life members,	4	15
Honorary members,	6	9
Associate members,	22	20
Corresponding Societies, Home,	10	12
Corresponding Societies, Foreign,	10	10
Periodicals, Home,	6	7
Periodicals, Foreign,	8	8
Libraries,	7	8
Subscribers,	6	11
Navy Department,	25	25
Bureau of Navigation,	...	50
	578	722

During the past year five members have died and seventeen resigned; none were dropped. Of the associate members, one resigned and one was dropped.

Lieut. J. D. J. Kelly, the Prize Essayist of 1882, has been transferred to Life membership, as have eight other members by payment of the fee required by the Constitution. Two gentlemen from civil life have also become Life members, thus increasing the number from four to fifteen. 104 members have joined, and John D. Jones, Esq., of New York, and Lieut. Alfred Collet, of the French Navy, have been elected to Honorary membership.

Nothing will more prominently show the growing confidence in the permanent success of the Naval Institute than this rapid increase in the roll of life members.

It is with pleasure that I call the attention of members to the unusual demand for the Proceedings during the past year; there have been sold 7 complete sets (Nos. 1 to 18 inclusive) equal to 126 copies; 339 single copies, and 1693 reprints of articles from the Proceedings. One set was presented to John D. Jones, Esq., by vote of the Institute, March 9th, 1882, and one set has been exchanged with the German Hydrographic office for a complete file of its publication. The executive committee has deemed it advisable to purchase back numbers in order to replenish the stock on hand, which is being rapidly depleted, and 80 copies have been so obtained.

The edition of No. 2 having been exhausted, and finding it impossible to obtain any copies by purchase, a second edition of 300 copies is now being printed, with which to meet future demands.

Since January, 1882, four numbers of the Proceedings have been issued, viz. No. 18, completing Vol. VII, 1881, and Nos. 19, 20, 21 of Vol. VIII, 1882. The material for No. 22 is now in the hands of the printer, and it is believed that the number will be ready for issue by February 1st, which will complete Vol. VIII.

Four essays in competition for the Prize of 1883 have been received. The following gentlemen have been invited to serve as the Judges of Award, viz.: Rear-Admiral George H. Preble of the Navy, and the Hon. Alexander H. Rice and Judge Josiah G. Abbott, both of Boston, and I am happy to say, have accepted.

I cannot close this report without publicly rendering thanks to the Corresponding Secretary of the Washington Branch, Lieut. John H. Moore, for his unceasing labors in behalf of the Institute, in obtaining new members, and especially in procuring orders for the sale of Proceedings from the various bureaux of the War and Navy Departments, and from others, which has been of material financial support to the Institute. I am indebted to him for the latest information regarding the official addresses of members, which has enabled me to render more certain the Proceedings reaching those for whom intended.

I have adopted the plan of obtaining receipts for every copy issued, which facilitates the detection of the loss of numbers and the correction of errors.

Very respectfully,

CHARLES M. THOMAS,

Secretary.

ANNAPOLIS, MD., *January 4th*, 1883.

TREASURER'S REPORT.

U. S. NAVAL ACADEMY,
ANNAPOLIS, MD., *March* 21, 1883.

TO THE PRESIDENT, OFFICERS AND MEMBERS
OF THE UNITED STATES NAVAL INSTITUTE.

Gentlemen:—The Treasurer's statement for the year 1882 is as follows:

RECEIPTS.

Balance on hand January 1, 1882,		$ 723 15
Received as dues,		2061 25
Received from sales of Proceedings and reprints,		1053 05
Received from yearly subscriptions,		34 30
Received from interest on U. S. Bonds,		24 00
Received from fees for life memberships,		300 00
Received from advertising,		10 00
Total receipts,		$4205 75

EXPENDITURES.

For postage, freight, expressage, telegraphing, and other incidental expenses at Annapolis,	$ 255 11	
For stationery at Annapolis,	43 06	
For incidental expenses at Branches,	44 73	
For printing Nos. 17, 18, 19, 20 and 21,	1990 75	
For engraving and lithographing for same,	394 50	
For purchase of back numbers,	60 25	
For purchase of $800 in U. S. 4 per cent. Bonds,	949 52	
For prize essay for 1882,	150 00	
		$3887 92
Balance of cash on hand Jan. 1, 1883,		$ 317 83

It will be seen by the foregoing that the Institute now owns $800 in United States 4 per cent. bonds, which cost $949.52. Their market value to-day is at least $960, and on them the Institute has already received $24 in interest. As the dues for each year are payable at the first of the year (and as a matter of fact the most of them are so paid), the resources of the Institute accrue and are received some months in advance of the necessity for their expenditure. There is, therefore, so far as the finances of the Institute can now be forecasted, no apparent reason why these bonds should not remain intact for many years, drawing quarterly interest, and with silent persistence, earning money for the Institute.

During the year 1882 the amount of $300 has been received as fees for ten life memberships—a welcome contribution of money, and of faith in the Institute's usefulness and stability.

The Treasurer's account since the 1st January, 1883, is as follows:

RECEIPTS.

Balance on hand, January 1, 1883,		$ 317 83
Received as dues,		711 71
Received from sales of Proceedings and reprints,		406 41
Received from yearly subscriptions,		23 45
		$1459 40

EXPENDITURES.

For postage, freight, expressage, telegraphing, and other incidental expenses at Annapolis,	$ 27 46	
For stationery at Annapolis,	12 13	
For incidental expenses at Branches,	10 75	
For printing extra edition of No. 2 (300 copies),	301 00	
For printing No. 22,	487 45	
For engraving and lithographing for same,	246 70	
For purchase of back numbers,	11 00	
		$1096 49
Balance of cash on hand March 21, 1883,		$362 91

The edition of No. 2 having become entirely exhausted, and the demand for complete sets of back numbers still continuing and even increasing, it was thought best to publish a new edition of 300 copies. Including these, the Institute has now on hand 2689 back numbers.

There is due the Institute from members in arrears $28 for 1881, $163.38 for 1882, and $911.50 for 1883.

Between the 1st of January, 1882, and March 21, 1883, there have been published six regular numbers of the Institute Proceedings, and the extra edition of No. 2 above mentioned.

The Treasurer congratulates the friends and patrons of the Institute in that, while it may not be all that it could be, and we hope not all that it will be, it is yet a settled and invulnerable success.

ROBERT W. ALLEN,
Paymaster U. S. N., and Treasurer U. S. Naval Institute.

THE PROCEEDINGS

OF THE

UNITED STATES NAVAL INSTITUTE.

Vol. IX. No. 1. 1883. Whole No. 23.

NAVAL INSTITUTE, ANNAPOLIS, MD.

MARCH, 1883.

CHEMICAL THEORY OF GUNPOWDER.

By H. DEBUS, Ph. D., F. R. S.

[*From the Philosophical Transactions of the Royal Society, Part* II, 1882.]

According to Bellani, the English army used cannon at the battle of Crecy in the year 1346. The correctness of this report has been doubted, since English and French writers in their description of the battle do not mention the use of cannon. However this may be, it is certain that from the middle of the 14th century the application of powder to the purposes of the art of war became more and more general, until towards the close of the Middle Ages heavy ordnance was used by all European armies. The effect of this new application of gunpowder upon the civilization of our race is usually considered to have been of the same importance as the invention of the art of printing or the discovery of America. And, although 536 years have passed away since the battle of Crecy was fought, we have to this day no satisfactory account of the chemical reactions which occur during the combustion of gunpowder, no theory to enable us to determine the quantitative relations of the products of combustion *à priori* from the composition of the powder. The attempts which have been made from time to time by eminent men to supply solutions of the problems indicated, have been, as is well known, unsuccessful.

In the following pages I propose to describe a theory which explains in a satisfactory manner the chemical reactions which occur during and after the explosion, not only of a powder of normal composition, but, generally, of a mixture of x molecules of saltpetre, y atoms of carbon, and z atoms of sulphur.

Until about the year 1856 the metamorphosis of gunpowder was represented in chemical text-books to take place according to the equation

$$2KNO_3 + 3C + S = K_2S + N_2 + 3CO_2.$$

This equation is obviously not correct, because besides sulphide, also sulphate and carbonate of potassium are formed.

After the publication of Bunsen's and Schischkoff's * classical investigation in 1857, the incorrectness of the equation was generally recognized, and the view expressed that the explosion of gunpowder could not be represented by a chemical equation on account of its complex nature. Passing by for the present the papers published between the years 1858 and 1874, I propose to take at once into consideration the most recent and important investigation by Noble and Abel; † I do so because we receive from the pages of their papers a very complete account of our present knowledge of the combustion of gunpowder.

Five different descriptions of powder were used in their experiments:

1. Pebble powder (P.); 2. Rifle large grain (R. L. G.); 3. Rifle fine grain (R. F. G.); 4. Fine grain (F. G.); and 5. Spanish pebble powder.

The first four descriptions were manufactured at Waltham Abbey.

It will be convenient for the purposes of reference to give in the following table the composition of these powders.

TABLE I.—*Showing the Composition of the Powders used by Noble and Abel.*

Constituents of powder.	Powders from Waltham Abbey.								Spanish.	
	P.		R. L. G.		R. F. G.		F. G.			
Saltpetre		74.67		74.95		75.04		73.55		75.30
Potassic sulphate		0.09		0.15		0.14		0.36		0.27
Potassic chloride		....		....		....		....		0.02
Sulphur		10.07		10.27		9.93		10.02		12.42
Charcoal: Carbon	12.12		10.86		10.67		11.36		8.65	
Charcoal: Hydrogen	0.42	14.22	0.42	13.52	0.52	14.09	0.49	14.59	0.38	11.34
Charcoal: Oxygen	1.45		1.99		2.66		2.57		1.68	
Charcoal: Ash	0.23		0.25		0.24		0.17		0.63	
Water		0.95		1.11		0.80		1.48		0.65

* Pogg. Ann., Bd. cii, p. 321, and Proc. Nav. Inst., Vol. V, p. 538.

† Phil. Trans., Vol. 165 (1875), p. 49, Vol. 171 (1880), p. 203.

Noble and Abel burnt from 100 to 700 grams of powder in hermetically closed steel cylinders.* The analyses of the products of combustion obtained in 31 experiments have been published, and of these it will be desirable to reproduce a few representative cases in Table II.

TABLE II.—*Containing the Results of Nine Experiments Calculated for 1 gram of Powder.*

Products of combustion.	F. G.			R. L. G.			P.		
K_2CO_3	0.2429	.2615	.3255	.3007	.3017	.3635	.2879	.3098	.3680
$K_2S_2O_3$	.1851	.1666	.0780	.1166	.0740	.0369	.1845	.0338	.0761
K_2SO_4	.1288	.1268	.1204	.1171	.1395	.0625	.0733	.0658	.0523
K_2S	.0000	.0196	.0252	.0230	.0337	.0565	.0128	.1055	.0220
KCNS	.0009	.0004	.0004	.0000	.0003	.0015	.0022	.0013	.0033
KNO_3	.0010	.0005	.0005	.0032	.0002	.0000	.0014	.0011	.0025
$(NH_4)_4H_2(CO_3)_3$	.0186	.0002	.0005	.0003	.0002	.0006	.0003	.0004	.0007
S	.0026	.0068	.0306	.0041	.0262	.0480	.0111	.0340	.0484
H_2S	.0090	.0080	.0088	.0041	.0127	.0067	.0129	.0084	.0086
CO	.0316	.0339	.0343	.0303	.0390	.0472	.0419	.0473	.0362
CO_2	.2689	.2678	.2650	.2597	.2610	.2677	.2630	.2770	.2710
CH_4	.0003	.0000	.0005	.0006	.0000	.0007	.0007	.0012	.0013
H	.0006	.0008	.0007	.0005	.0007	.0005	.0005	.0005	.0005
N	.1096	.1071	.1096	.1201	.1108	.1077	.1075	.1139	.1090
No. of experiment.	XL.	XIX.	LXXV.	I.	IV.	XXXIX.	XXXVIII.	XIV.	LXXVII.

From this table it is clear that not only powders of different description, but also mixtures of the same nature, will yield during combustion the products in variable quantities. The salts of potassium, especially the hyposulphite and sulphide, vary considerably in different experiments.

Noble and Abel draw the following conclusions from the results of their investigations:

1. "The variations in the composition of the products of explosion furnished in close chambers by one and the same powder, under different conditions as regards pressure, and by two powders of similar composition under the same conditions as regards pressure, are so considerable, that no value whatever can be attached to any attempt to give a general chemical expression to the metamorphosis of a gunpowder of normal composition (p. 137).

"Any attempt to express, even in a comparatively complicated chemical equation, the nature of the metamorphosis which a gunpowder of average composition may be considered to undergo when

* Phil. Trans., Vol. 165 (1875), p. 61.

exploded in a confined space, would therefore only be calculated to convey an erroneous impression as to the simplicity or the definite nature of the chemical results and their uniformity under different conditions, while it would, in reality, possess no important bearing upon an elucidation of the theory of explosion of gunpowder (p. 85).

2. "The proportions in which the several constituents of solid powder residue are formed, are quite as much affected by slight accidental variations in the conditions which attend the explosion of one and the same powder in different experiments, as by decided differences in the composition as well as in the size of grain of different powders (p. 137).

3. "Very small grain powder, such as F. G. and R. F. G., furnish decidedly smaller proportions of gaseous products than a large grain powder (R. L. G.), while the latter again furnishes somewhat smaller proportions than a still larger powder (pebble), though the difference between the gaseous products of these two powders is comparatively inconsiderable.

4. "In all but very exceptional results, the solid residue furnished by the explosion of gunpowder contains as important constituents, potassium carbonate, sulphate, hyposulphite and sulphide, the proportion of carbonate being very much higher, and that of sulphate very much lower than stated by recent investigators."

The view of Noble and Abel may be briefly stated as follows:

One and the same description of powder, exploded several times in succession, will yield the products of combustion, in the different experiments, in variable proportions; hence, the metamorphosis of gunpowder cannot be represented by a chemical equation.

One might suppose that, perhaps, the pressure developed during explosion had an influence on the quantities of the products of combustion. From a comparison of the analytical results and the corresponding pressures, published by Noble and Abel, this, however, appears not to be the case.* (See p. 85 of their first memoir.)

According to Noble and Abel, the chemical metamorphosis of gunpowder during explosion is a very complicated process, which cannot be explained with the data at their disposal. Berthelot† arrived at a different conclusion.

* An increase of pressure appears to diminish the amount of carbonic oxide. But this is not always the case, and when it does occur, it is not sufficient to explain the variations in the other products of combustion.

† Comptes Rendus, tom. lxxxii, p. 487.

The composition of the powders of Waltham Abbey can, according to him, be represented by the symbols

$$2KNO_3 + 3C + S$$

which require for 100 parts of powder:

Saltpetre	74.8
Carbon	13.3
Sulphur	11.8

The analysis gave:

Saltpetre	73.55	to	75.04
Carbon	10.67	"	12.12
Sulphur	9.93	"	10.27

The combined weights of potassic sulphocyanate, ammonic carbonate, hydrogen, marsh gas, and sulphuretted hydrogen amount, according to Table II, to about 1.5 per cent. They evidently originate from secondary reactions, and may, accordingly, be neglected in the following considerations.

A theory of the explosion of gunpowder ought to explain the formation of potassic carbonate, potassic sulphate, potassic sulphide, carbonic acid and carbonic oxide. Potassic hyposulphite is not a primary product, but is formed during the analysis of the powder residue.

If we select two from several experiments published by Noble and Abel, viz. one in which the maximum amount of potassic carbonate and the minimum of sulphate were produced, and another which yielded the largest quantity of potassic sulphate and the smallest of carbonate, then, according to M. Berthelot, the explosion which produced the results of the first case may be represented by three equations—

$\frac{1}{3}$ of the powder was transformed according to equation

$$2KNO_3+3C+S=K_2S+3CO_2+N_2, \quad \text{I.}$$

$\frac{1}{2}$ according to

$$2KNO_3+3C+S=K_2CO_3+CO_2+CO+N_2+S, \quad \text{II.}$$

$\frac{1}{6}$ according to

$$2KNO_3+3C+S=K_2CO_3+1.5CO_2+0.5C+S+N_2 \quad \text{III.}$$

and in the second case, with a maximum of potassic sulphate,

$\frac{1}{3}$ of the powder was transformed according to equation I,
about $\frac{1}{2}$ according to III,
$\frac{1}{8}$ according to

$$2KNO_3+3C+S=KS_2O_4+2CO+C+N_2, \qquad \text{IV.}$$

and $\frac{1}{12}$ according to

$$2KNO_3+3C+S=K_2SO_4+CO_2+C_2+N_2 \qquad \text{V.}$$

Between the limits marked by these two cases are contained all the experimental results of Noble and Abel. If, therefore, we assume that in a given experiment one portion of the powder used burnt according to the equations of the first, and the rest according to those of the second case, the calculated results will agree with the observations. And if the proportions of powder, which are transformed according to the one or other system of equations, be changed from experiment to experiment, the quantities of the products of combustion obtained in each experiment can be calculated in a satisfactory manner.

The assumption that during explosion one portion of the powder is transformed according to one, and another portion according to another, equation or system of equations is justified in the opinion of M. Berthelot by the further assumption, that the local conditions in a mass of burning powder are not the same in all parts, and that the cooling is too rapid to allow the products to assume a state of chemical equilibrium.

If the products were left in contact at a high temperature for a longer time, they would react upon each other, and the final result would be the same as that represented by equation V, to which corresponds the greatest evolution of heat.

This theory of M. Berthelot is very ingenious, but does not agree with experience. Considerable amounts of carbon ought to be left free at the end of each expl sion. In twenty-eight experiments of Noble and Abel no free carbon was left, and only in three cases small insignificant quantities had escaped combustion. The equations III, IV and V cannot be applied to the combustion of the powders of Waltham Abbey. But even if the theory were correct, it would possess no practical value, because the quantities of the powder which would burn according to each of the two systems of equations could not be known *à priori*, but would have to be found by experiment.

Berthelot invented his theory in order to explain the remarkable result of Noble and Abel's experiments, that the same description of

powder, or powders of similar composition, yield the products of explosion, in different experiments, in variable proportions.

We will now proceed to show that this result can be explained, without hypothesis or theory, in a very simple manner.

For this purpose it is desirable to express the analytical results of Noble and Abel in a manner different from the one adopted by these investigators.* If we divide the numbers of Table II by the corresponding molecular weights, we obtain another table expressing the number of molecules of the products obtained in the different experiments by the explosion of 1 gram of powder. For experiment XIX we have:

K_2CO_3	0.2615 gram or	0.00189 mol.
K_2SO_4	0.1268 "	0.00072 "
$K_2S_2O_3$	0.1666 "	0.00087 "
K_2S_2	0.0252 "	0.00017 "
S	0.0012 "	0.00004 atom.
CO_2	0.2678 "	0.00608 mol.
CO	0.0339 "	0.00121 "
N	0.1071 "	0.00765 atom.
H_2S	0.0080 "	0.00023 mol.
CH_4	0.0000 "	0.00000 "
H	0.0008 "	0.00080 atom.
KCNS	0.0004 "	
KNO_3	0.0005 "	
$Am_4H_2(CO_3)_3$ . .	0.0002 "	

Potassic carbonate, sulphate, sulphide, and hyposulphite, carbonic acid and carbonic oxide, nitrogen and sulphuretted hydrogen together form more than 98 per cent. of the exploded powder; accordingly, hydrogen, marsh gas, ammonic carbonate, potassic sulphocyanate and undecomposed saltpetre may, as non-essential products, be left out of consideration.

Potassic carbonate, sulphate, hyposulphite and sulphide contain very nearly the entire amount of potassium of the exploded powder. If, therefore, we add the number of molecules of these bodies and multiply the sum by two, we obtain the number of molecules of saltpetre in 1 gram of powder. In order to compare the results of experiments made with the same or with different descriptions of gunpowder it is desirable to calculate these results, not, as is usually done,

* Noble and Abel discuss only the percentage quantities of the products of explosion.

for the same quantity of powder, but for such quantities as contain equal amounts of saltpetre or oxygen.

The products of Experiment XIX contain 0.00730 atom of potassium and are derived from a weight of powder containing 0.0073 mol. of saltpetre. The same products contain 0.00189 mol. of K_2CO_3, hence:

$$0.00730 : 0.00189 :: 16 : x \text{ and } x = 4.14.$$

And if the same mode of calculation is extended to the other products, we obtain

$$\begin{aligned} &4.14K_2CO_3 + 1.58K_2SO_4 + 13.3CO_2 + 8.38N_2 \\ &\quad + 1.90K_2S_2O_3 + 2.65CO + 0.08S \\ &\quad + 0.37K_2S_2 \qquad\qquad + 0.5H_2S \end{aligned}$$

and, from these numbers, the following composition of the F. G. powder,

$$\begin{aligned} &16KNO_3 + 20.09C + 6.70S \\ &+ 0.76N + 1.0H \\ &\qquad + 5.69O. \end{aligned}$$

By a similar calculation we obtain:

Experiment LXXV.

$$\left.\begin{array}{l} 5.10K_2CO_3 + 13.08CO_2 + 0.56H_2S \\ 1.50K_2SO_4 + 2.65CO \\ 0.89K_2S_2O_3 + 8.5N_2 \\ 0.48K_2S_2 + 1.58S \end{array}\right\} = \left\{\begin{array}{l} 16KNO_3 + 20.83C \\ 0.5N_2 \quad + 6.38S \\ 4.78O \\ 1.12H \end{array}\right.$$

Experiment IV.

$$\left.\begin{array}{l} 4.75K_2CO_3 + 12.92CO_2 + 0.80H_2S \\ 1.74K_2SO_4 + 3.03CO \\ 0.85K_2S_2O_3 + 8.6N_2 \quad + 1.11S \\ 0.65K_2S_2 \end{array}\right\} = \left\{\begin{array}{l} 16KNO_3 + 20.7C \\ 6.65S \quad + 0.6N_2 \\ +1.60H \\ +4.63O \end{array}\right.$$

Experiment XXXIX.

$$\left.\begin{array}{l} 5.70K_2CO_3 + 13.18CO_2 + 0.41H_2S \\ +0.78K_2SO_4 + 3.64CO \\ +0.41K_2S_2O_3 + 8.3N_2 \quad + 2.14S \\ +1.10K_2S_2 \end{array}\right\} = \left\{\begin{array}{l} 16KNO_3 + 22.52C \\ +6.35S + 0.3N_2 \\ +0.82H \\ +3.45O \end{array}\right.$$

Experiment XIV.

$$\left.\begin{array}{l} 4.77K_2CO_3 + 13.44CO_2 + 0.51H_2S \\ +0.79K_2SO_4 + 3.62CO \\ +0.36K_2SO_3 + 8.67N_2 \quad + 0.21S \\ +2.04K_2S_2 \end{array}\right\} = \left\{\begin{array}{l} 16KNO_3 + 21.83C \\ +6.31S + 0.67N_2 \\ +1.05H \\ +1.05O \end{array}\right.$$

Experiment LXXVII.

$$\left.\begin{array}{l} 5.95K_2CO_2 + 13.78CO_2 + 0.55H_2S \\ + 0.67K_2SO_4 + 2.88CO \\ + 0.89K_2S_2O_3 + 8.7N_2 \quad + 2.93S \\ + 0.44K_2S_2 \end{array}\right\} = \left\{\begin{array}{l} 16KNO_3 + 22.61C \\ + 6.81S + 0.7N_2 \\ + 1.10H \\ + 5.64O \end{array}\right.$$

These equations represent only the quantitative relations between the constituents of the powders and the products of explosion, and, accordingly, fractions of atoms and molecules are admissible.

Experiments XIX and LXXV were made with F. G., Experiments IV and XXXIX with R. L. G., and Experiments XIV and LXXVII with P. powder of Waltham Abbey.

It will be noticed by comparing two experiments, made with the same description of powder, that the composition of the powder deduced from one of the experiments exhibits considerable differences from the composition derived from the other experiment, and neither of them agrees with the composition found by direct analysis.

The composition of the R. L. G. powder may serve as an example.

According to Experiment IV . .		$16KNO_3 + 20.7C + 6.65S + 4.63O$
"	" Experiment XXXIX	$16KNO_3 + 22.52C + 6.35S + 3.45O$
"	" Analysis of powder	$16KNO_3 + 19.51C + 6.92S$

The products of combustion of Experiment IV contain 1.2, and of Experiment XXXIX 3 atoms more carbon than the powder used in these experiments, or in other words, the products of explosion in Experiment XXXIX were found to contain 1.67 per cent. more carbon than the R. L. G. powder which was exploded.

The results of other experiments, made by Noble and Abel, differ from each other in a similar manner.

One is forced to conclude either that the methods of analysis adopted by Noble and Abel do not yield exact results, or that the powders exploded did not possess the composition which was attributed to them.

Gunpowder is a mechanical mixture of saltpetre, charcoal and sulphur. It can hardly be expected that such a mixture should, even if the greatest care has been taken by the manufacturer, be perfectly homogeneous. Moreover, the burning of wood into charcoal will not always yield a product containing the same percentage amount of carbon, and as gunpowder is a mixture of 75 parts of saltpetre, 10 of sulphur and 15 of charcoal, it appears *à priori* probable that the same description of powder from the same manufacturer will

not always possess the same percentage composition. The amount of carbon, more particularly, may be expected to vary more or less.

In order to test this conclusion by experiment, I requested the late Mr. Wills to analyse a sample of R. L. G. and one of pebble (P.) powder, both obtained from the Royal Arsenal, Woolwich. His results, placed side by side with those of Noble and Abel, are given below.

	R. L. G.		P.	
	Noble and Abel.	Wills.	Noble and Abel.	Wills.
Saltpetre,	74.95	75.10	74.67	74.26
Sulphur,	10.27	8.96	10.07	9.51
Charcoal—				
Carbon,	10.86	12.09	12.12	11.58
Hydrogen,	0.42	0.54	0.42	0.51
Oxygen,	1.99	2.12	1.45	2.55
Ash,	0.25	0.20	0.23	0.33
Water,	1.11	0.85	0.95	0.76
	99.85	99.86	99.91	99.50

It will be noticed that the amounts of carbon and sulphur found by Wills differ considerably from those found by Noble and Abel. But the best proof that the same description of powder from the same works may vary much in composition has been furnished by Noble and Abel themselves. In their first memoir they assign to R. L. G. powder the above composition; in their second paper "On Fired Gunpowder" they publish the following analysis:

Saltpetre,	74.43
Sulphur,	10.09
Charcoal—	
Carbon,	12.40
Hydrogen,	0.40
Oxygen,	1.27
Ash,	0.21
Water,	1.05
	99.85

The sample used in the first analysis was taken from the top, the one employed in the second from the bottom of the same barrel. Two analyses of powder out of the same barrel, executed by the same chemists, gave amounts of carbon which differ from each other by no

less than 1.54 per cent.! We will now consider the effect of such a difference in the percentage of carbon on the relative quantities of the products of combustion.

If in one experiment 100 grams of powder containing 75 parts of saltpetre, 10 parts of sulphur, and 10.86 parts of carbon, and in a second experiment 100 grams of powder with 74.43 parts of saltpetre, 9 parts of sulphur, and 12.40 parts of carbon had been exploded, then, *cæteris paribus*, in the second experiment more potassic carbonate, more sulphide and less sulphate must have formed than in the first, and the quantitative differences of the same products furnished by the two experiments would be almost as great as the greatest differences actually observed by Noble and Abel for the same description of powder in the whole series of their experiments. We arrive in this manner at a very simple explanation of the experimental results upon which Noble and Abel have based the conclusions mentioned under No. 1 and 2 on p. 525, without the necessity of having recourse to a theory like the one advanced by M. Berthelot, or renouncing all explanation like Noble and Abel.

It follows from Table I that the differences of composition between P., R. L. G., R. F. G., and F. G. powders, one compared with the other, are not greater than the differences between two samples of R. L. G. powder taken out of the same barrel. From this it appears probable that only one mixture of saltpetre, charcoal, and sulphur is prepared at Waltham Abbey, and that from this one mixture the powders P., R. L. G., R. F. G., and F. G., differing only in size of grain and, perhaps, density, are manufactured. We may take then for the composition of the said powders the mean of the numbers of all published analyses. Taking into consideration only the saltpetre, sulphur, and carbon, we obtain—

R. L. G. 1st analysis by Noble and Abel	$16KNO_3+19.51C+6.92S$
" 2d " "	$16KNO_3+22.40C+6.83S$
F. G.	$16KNO_3+20.80C+6.8S$
P.	$16KNO_3+21.86C+6.79S$

and for the mean $16KNO_3+21.14C+6.83S$.

If also the analyses of the late Mr. Wills are taken into consideration, then the mean composition of the powders of Waltham Abbey would be represented by the symbols

$$16KNO_3+21.18C+6.63S$$

The differences of composition found by analysis for the same description of powder are also of great importance in the calculations of the analytical results of the products of explosion. Noble and Abel determine the potassium in x parts of the solid powder residue, and by means of the number so obtained calculate the weight of the total residue. The amount of potassium in the quantity of powder exploded is known from the analysis of the powder, and as the whole of this potassium must reappear in the solid residue, it is easy to find the total residue if the weight of potassium in x parts of it is known.

The total weight of the powder residue subtracted from the weight of the powder used in the experiment gives as difference the total weight of the gases produced by the explosion.

This mode of calculation requires that the exact composition of the powder used in each experiment should be known. Messrs. Noble and Abel assume the composition of the powders of Waltham Abbey, P., R. F. G., and F. G., to be constant; they also consider in their first memoir that of R. L. G. to be so, but in their second memoir they base the calculations of the later experiments on the second analysis of this description of powder. This assumption is, as a matter of fact, not correct; on the contrary, we may take it as highly probable that in any two experiments made by Noble and Abel with the same class of powder, the powder used in the one experiment was not exactly of the same composition as the powder used in the other. Accordingly the weight of the solid residue as calculated by Noble and Abel will have been found in some experiments too high, in others too low, and as a consequence of this the total weight of the gaseous products cannot have been exact. The correctness of this is proved by the differences between the composition of the powders calculated from the products of combustion, and the composition deduced from direct analysis (see pp. 9, 10). These errors will, however, compensate each other if we take the mean of the analytical results of all the experiments.

Before we proceed to do so it will be desirable to consider another circumstance which is not without influence on the final results of Messrs. Noble and Abel.

They burnt their powders in steel cylinders in quantities from 100 to 750 grams, so that the solid products of combustion after explosion remained from 60 to 120 seconds in contact in a fluid condition at a high temperature. Amongst these products we have not, as is

usually assumed, potassium monosulphide, but disulphide, free sulphur, and potassium carbonate. But a mixture of polysulphides of potassium and potassium carbonate at a bright red or a white heat has a most powerful corroding effect upon metals. It is well known that the celebrated Stahl was of opinion that Moses had dissolved the golden calf of the Israelites by means of a polysulphide of potassium.

"And he took the calf which they had made, and burnt it in the fire, and ground it to powder, and strewed it upon the water, and made the children of Israel drink of it."—(Exod. xxxii. 20.)

Sulphur and ash of wood were known to the Jews, and these, at a high temperature, form liver of sulphur, capable of dissolving gold. The affinity of iron for sulphur is very strong. We may expect that, according to temperature, pressure, time of cooling, and last but not least, the condition of the surface of the cylinder, more or less of the sulphur of the powder would unite with the iron of the apparatus. This would have the same effect upon the products as if a powder with less sulphur had been burnt. If 400 grams of powder of the average composition had been exploded, and 10 grams of its sulphur were to unite with the iron of the apparatus, the potassium carbonate produced would be about 0.20 times greater than the amount obtained by the combustion of the same quantity of powder without this removal of sulphur by the iron of the apparatus.

According to the description given by Noble and Abel of the solid powder residue, considerable quantities of ferrous sulphide were contained in it. Hence the variations in the quantities of the products of combustion of powders exploded in Noble and Abel's apparatus will partly be due to the chemical action of iron and sulphur at high temperatures.

It will be observed by an inspection of the equations on pages 8 and 9, that considerably more oxygen was found in the products of combustion than was contained in the saltpetre of the exploded powder. This excess of oxygen cannot have been derived from the charcoal, or the moisture of the powder, because if it had, equivalent quantities of hydrogen ought to have been liberated. Charcoal contains more hydrogen than is necessary to form water with its oxygen. It is this excess of hydrogen which is set free, or which unites with sulphur, carbon or nitrogen, forming sulphuretted hydrogen, marsh gas, or ammonia.

Hence, the excess of oxygen in the products of explosion must originate from some other source. Noble and Abel, like Linck,

Karolyi and others, adopted the method proposed by Bunsen and Schischkoff for the analysis of the solid powder residue. This method requires that the aqueous solution of the substance should be digested with cupric oxide in order to convert the potassic sulphide into hydrate. The question suggested itself whether or not oxygen from the cupric oxide had formed with potassic sulphide, sulphate or hyposulphite.

27.3 grams pure potassic hydrate were dissolved in water, which previously had been boiled in order to expel the air, and the solution divided into two equal parts. One of these parts was saturated with sulphuretted hydrogen in an atmosphere of hydrogen and then mixed with the other, and the solution of potassic sulphide, so obtained, digested with powder of sulphur in sufficient quantity to produce pentasulphide. The analysis of this liquid gave the following results:

10 cub. centims. diluted with previously boiled water were acidulated with hydric chloride and heated to the boiling point. A precipitate of 1.094 grams of sulphur was obtained. The filtrate evaporated to dryness and ignited, the dry residue moistened with hydric chloride, and then raised to a red heat gave 1.387 grams of potassic chloride, corresponding to 0.726 gram of potassium. On the assumption that 1 atom of sulphur had escaped as sulphuretted hydrogen, the liquid, according to these determinations, contains sulphur and potassium in the proportion of 4.67 atoms of the former to 2 atoms of the latter.

10 cub. centims. of the sulphide mixed with a solution of zinc sulphate, and the filtrate tested with an iodine solution in presence of some starch, required 0.2 cub. centim. of the iodine liquid in order to produce a blue color. 1 cub. centim. of the iodine solution corresponded to 1 cub. centim. of a solution of sodium hyposulphite containing 24.8 grams of the salt in 1 litre.

Therefore, 10 cub. centims. of the polysulphide of potassium contain:

0.0038 gram potassic hyposulphite
2.119 grams potassic polysulphide.

To check these numbers, Mr. Cowper, at my request, dissolved the zinc sulphide in hydric nitrate of 1.5 sp. grav., and determined the zinc and the sulphur in the solution according to the usual methods.

He obtained:

Sulphur	1.285 grams
Zinc	0.556 gram,

or for every atom of zinc 4.69 atoms of sulphur.

180 cub. centims. of the solution of potassic polysulphide were digested in a hermetically closed flask with pure and previously ignited cupric oxide at common temperatures. The liquid assumed a brown color, which still could be observed after two days' digestion. The flask was now placed in water of 35° C., whereupon the color rapidly disappeared. The contents of the flask were now placed upon a filter, the cupric oxide and sulphide well washed, and filtrate and wash water united and kept in a closed bottle.

I. 25 cub. centims. of the liquid so prepared, neutralized with acetic acid, mixed with some starch solution, required 24.6 cub. centims. of iodine solution for the production of the blue color.

25 cub. centims. in another experiment required 24 cub. centims. iodine solution.

25 cub. centims. in a third experiment required 24.2 cub. centims. iodine solution.

The mean of these experiments is 24.26 cub. centims. of iodine solution for 25 cub. centims. of the filtrate, hence 100 cub. centims. of the united filtrate and wash water contain 1.844 grams of potassic hyposulphite.

II. 100 cub. centims. of the same filtrate evaporated with pure hydric sulphate gave 3.653 grams of potassic sulphate, which dissolved in water to a clear and neutral liquid. A similar quantity of hydric sulphate to that which had been used in this experiment, and out of the same bottle, left no residue after evaporation. 3.653 grams of K_2SO_4 contain 1.6375 grams of potassium, 1.844 grams of $K_2S_2O_3$ contain 0.757 gram of potassium; therefore, more than one-third, nearly one-half, of the potassium of the $K_2S_{4.67}$ in the original solution appears after treatment with cupric oxide as potassic hyposulphite.

The presence of potassic hyposulphite is assumed on account of the behavior of the liquid with iodine solution. A direct proof of its presence appeared to be desirable.

Reactions of the Filtrate of the Cupric Oxide.

a. Hydric chloride caused turbidity after some time, probably from sulphur.

b. Barium chloride, a white precipitate, only partly soluble in hydric chloride.

c. Cupric sulphate gave after neutralization with acetic acid a blue precipitate, which turned dark brown at 70–80° C.

A mixture of sodic hyposulphite, potassic acetate and cupric sulphate behaved in a similar manner.

d. Lead acetate and silver nitrate, respectively, gave the same reactions as they do with a solution of sodic hyposulphite.

122 cub. centims. of the strongly alkaline filtrate were neutralized with acetic acid and allowed to evaporate over hydric sulphate under the receiver of an air-pump. After a few days a great number of prismatic crystals were observed. These crystals warmed with alcohol fused into an oily liquid, which recrystallized on cooling and did not dissolve in alcohol.

Alcohol added to the mother-liquor of the crystals produced a crystalline precipitate.

The original crystals and the crystalline precipitate united weighed 2.634 grams.

According to the determination with iodine solution 122 cub. centims. of the filtrate from the cupric oxide contain 2.249 grams anhydrous, or 2.604 grams hydrated salt of the formula $3K_2S_2O_3, 5H_2O$. The crystals dissolved easily in 3 cub. centims. of water with absorption of heat; from this solution 2.457 grams of salt were reobtained.

0.497 gram of the same, dissolved in water and mixed with a solution of strontium chloride, gave, after two days' standing, a very small precipitate.

0.903 gram of the salt, dissolved in 50 cub. centims. of water, gave on addition of 1 gram of barium chloride a white precipitate, which left, after treatment with boiling water, 0.017 gram of barium sulphate. The filtrates of the barium sulphate yielded a fine crop of barium hyposulphite.

As this salt is, according to my experience, easily obtained in a pure form, the whole of the potassium hyposulphite was converted into the barium compound for the following analytical determinations.

0.882 gram baric hyposulphite boiled with hydric nitrate gave 0.763 gram of baric sulphate; the filtrate of this gave, on addition of barium chloride, another quantity of the same salt, which, after ignition and treatment with hydric chloride, weighed 0.753 gram.

Therefore in 100 parts:

	Experiment.	Theory.	
		BaS_2O_3.	BaS_2O_3, H_2O.
Barium, . . .	50.86	51.70	48.41
Sulphur, . . .	23.60	24.15	22.61

The potassium salt from which the barium hyposulphite had been prepared gave the following reactions:

a. Hydric chloride produced, a few moments after its addition, a slightly yellow turbidity.

b. Cupric sulphate gave a slight turbidity at common temperatures; on boiling, a copious brown precipitate.

c. Lead acetate, a white precipitate, which did not change its color at 100° C.

d. Ferric chloride gave the usual violet color.

e. Silver nitrate, a white precipitate, which turned black at higher temperatures.

According to these experiments there can be no doubt that, by the treatment of a solution of a mixture of potassic penta- and tetra-sulphides with cupric oxide, large quantities of potassic hyposulphite are formed.

The mother-liquor of the potassic hyposulphite, from which this salt had been removed by means of alcohol, was left to evaporate *in vacuo*. The crystalline residue, heated in a platinum crucible, produced an oily liquid, which crystallized on cooling, like potassic acetate, and weighed 2.616 grams.

It was converted by means of hydric sulphate into 2.404 grams of potassic sulphate.

2.616 grams of potassic acetate should give, according to theory, 2.320 grams of potassic sulphate. If we assume that, in the solution obtained by the treatment of potassic polysulphides with cupric oxide, only potassic hyposulphite and potassic hydrate are present, then, according to the numbers given on page 536, 122 cub. centims. of the filtrate from the cupric oxide should have given 2.697 grams potassic acetate, instead of 2.616 as found by experiment.

Hence we may conclude that 100 cub. centims. of the filtrate from the cupric oxide contain:

1.844 grams potassic hyposulphite,
1.263 " " hydrate,

and a very small amount of potassic sulphate.

At my request, Mr. Cowper digested solutions of the other sulphides of potassium with cupric oxide and examined the products for potassium hyposulphite. He found that in a solution of potassic tersulphide (K_2S_3) nearly $\frac{1}{2}$, in one of potassic disulphide about $\frac{1}{5}$, and in one of potassic sulph-hydrate about $\frac{1}{12}$ of the potassium appears after treatment with cupric oxide as hyposulphite. All these experiments lead to the conclusion that the potassic hyposulphite found in solid powder residues by Bunsen and Schischkoff's method had been formed during the analysis of the said residues, and was not one of the original products of explosion. This conclusion is supported by the observation of Pape,* according to which potassic hyposulphite is decomposed at 225° C. into sulphate and pentasulphide of potassium.

At the conclusion of my experiments in July, 1879, I communicated the results to Mr. Abel, and he has since then confirmed my observations.

Noble and Abel say at the end of their second memoir (Phil. Trans., 1880, p. 277), "that although it would seem that in certain cases and under certain exceptional circumstances potassium hyposulphite does exist as a secondary, it exists in no case as a primary product, and should not, therefore, be reckoned among the normal constituents of powder residues."

Wishing to obtain a clear conception of the mode of action of cupric oxide in the analysis of a powder residue, I instituted the following experiments:

6.157 grams potassic sulphate and 8.541 grams of potassic carbonate were dissolved in 100 cub. centims. of water; the solution filled the space of 103.5 cub. centims.

10 cub. centims. of this liquid were mixed with 5 cub. centims. of a solution containing:

Potassium	0.389 gram.
Sulphur	0.498 "

or 3.12 atoms of sulphur for every 2 atoms of potassium.

The solution so prepared was then digested for two days with previously ignited cupric oxide in a well-stoppered bottle, at ordinary temperatures.

The mixture appeared brown, but became decolorized at 35° C.

The contents of the bottle were placed upon a filter; the black oxide and sulphide were well washed with boiling water, and both, filtrate and wash water united, were kept in a stoppered bottle. They filled the space of 578 cub. centims.

111 cub. centims. of the filtrate required 3.7 cub. centims. of the iodine solution.

192 cub. centims. of the filtrate required 6.3 cub. centims. iodine liquid. Hence, the entire filtrate contained 0.3623 gram of potassic hyposulphite.

* Pogg. Ann., Bd. cxxii, p. 408.

91 cub. centims. of the filtrate acidulated with hydric chloride, boiled for some minutes, separated from precipitated sulphur by filtration, and mixed with baric chloride, gave a precipitate of baric sulphate weighing 0.158 gram. The whole filtrate therefore contains 0.749 gram of potassic sulphate.

91 cub. centims. of the filtrate, acidulated with hydric chloride and evaporated to dryness, gave, after treatment of the residue with hydric sulphate, 0.395 gram potassic sulphate. From this number it follows that the entire filtrate contained 1.124 grams of potassium.

91 cub. centims. of the filtrate gave, with manganous sulphate, a precipitate, which generated with dilute hydric sulphate 0.042 gram of carbonic acid. 578 cub. centims. of the filtrate contain 0.266 gram carbonic acid, corresponding to 0.834 gram potassic carbonate.

From the solution of the precipitate caused by manganous sulphate, 0.094 gram of Mn_3O_4 was obtained, corresponding to 0.597 gram for the entire filtrate; 0.461 gram of this is derived from manganous carbonate, the remainder, 0.136 gram of Mn_3O_4, from the manganous hydrate precipitated by potassic hydrate. 0.136 gram of Mn_3O_5 corresponds to 0.139 gram of potassium or 0.310 gram of K_2S_3. The black cupric oxide and sulphide was dissolved in concentrated hydric nitrate and the solution precipitated by baric chloride; the weight of the baric sulphate was found to be 2.754 grams.

The following table contains the results of these experiments:

	Composition of the original solution.	Found by analysis.
Potassic carbonate	0.829	0.834
" sulphate	0.597	0.749
" tersulphide	0.887	0.310
" hyposulphite . . .	0.000	0.362
Potassium	1.124	1.124
Sulphur in CuO	0.000	0.378
" in $K_2S_2O_3$	0.000	0.122

A considerable error attaches to the determination of the sulphur. The cupric oxide had been ignited in a Hessian crucible. From this, it appears, it became contaminated with silica and alumina. The baric sulphate, precipitated from the solution of the cupric oxide in hydric nitrate by baric chloride, contained a copper compound which I regard as a silicate, since it could not be got rid of even after long-continued boiling with hydric chloride.

The analysis gives quite a wrong idea of the composition of the original solution. Not only is a portion of the potassic tersulphide converted into hyposulphite, it even appears that some has been oxidized into sulphate.

The following experiments prove the absence of sulphates in the reagents used for the above determinations.

15 cub. centims. of solution of potassic tersulphide, acidulated with hydric chloride, boiled, filtered and precipitated with baric chloride gave only 0.0005 gram baric sulphate. 80 grams of cupric oxide were dissolved in hydric chloride and the solution mixed with 1 gram of baric chloride; even after two days' standing no precipitate could be observed.

0.854 gram potassic carbonate, examined in a similar manner, was found to contain only 0.0007 gram of sulphate.

1 gram of sodic hyposulphite in 100 cub. centims. of water gave with barium chloride a crystalline precipitate which proved to be completely soluble in boiling water. Baric chloride, added to the water used in the experiments, and hydric chloride caused no precipitate.

1 gram of sodium hyposulphite was dissolved in 200 cub. centims. of water, hydric chloride added, and the solution boiled during three-quarters of an hour. Baric chloride precipitated 0.022 gram of baric sulphate. Another similar experiment yielded 0.028 gram baric sulphate.

From these experiments it is clear that in a solution containing hyposulphites and sulphates, the latter cannot accurately be determined by the ordinary method. The error from this source is, however, not sufficiently great to account for the discrepancy between the sulphate taken and found in the experiment described on page 18, and exhibited in the table given on that page.

Accordingly, it appears probable that by the action of cupric oxide upon potassic tersulphide, in *presence of potassic carbonate*, not only potassic hyposulphite but also a potassic sulphate is formed.

15 cub. centims. of a solution of potassic sulphide were acidulated by addition of hydric chloride, and by boiling and filtration were separated from the precipitated sulphur. The potassic chloride left, after evaporation of the filtrate from the sulphur, was converted, by means of hydric sulphate, into potassic sulphate. The weight of this salt was found to be 2.554 grams.

5 cub. centims. of potassic sulphide solution, mixed with potassic hydrate and oxidized by chlorine, yielded 3.58 grams of baric sulphate. 10 cub. centims. of potassic sulphide solution, precipitated by zinc sulphate, and the filtrate from the zinc sulphide examined by means of iodine solution for hyposulphites, gave numbers which indicated in 15 cub. centims. of the sulphide solution 0.114 gram of potassic hyposulphite. Sulphuric acid was not found in the sulphide solution.

15 cub. centims. of potassic sulphide solution, out of the same bottle from which the quantities used in the above experiments had been taken, were mixed with solutions of 1.188 grams of potassic sulphate, and of 1.650 grams of potassic carbonate.

The mixture so prepared had the following composition:

	Grams.		Grams.
Potassic carbonate	1.650		
" sulphate	1.188		
" sulphide	2.534	Sulphur	1.4366
		Potassium	1.0977
" hyposulphite	0.114	Sulphur	0.0384
		Potassium	0.0468

It was digested for a few days in a closed flask with 40 grams of cupric oxide at common temperatures, and finally decolorized by the raising of its temperature for a short time to 35°C.

The contents of the flask were placed upon a filter and the oxide and sulphide washed with hot water. The volume of filtrate and wash-water measured 1081 cub. centims.

The analysis of the liquid gave the following results:

200 cub. centims. gave 0.394 gram of baric sulphate; according to these numbers 1081 cub. centims. contain 1.589 grams of potassic sulphate.

312 cub. centims. were precipitated with manganous sulphate. From the precipitate so obtained, 0.140 gram of carbonic acid was developed by means of sulphuric acid, and 0.443 gram of Mn_3O_4, prepared by the usual method. Hence, 1081 cub. centims. of filtrate contain 1.521 grams of potassic carbonate and 0.708 gram of potassium in the form of hydrate.

139 cub. centims. of the liquid required 6.4 cub. centims. of iodine solution. Therefore, 1081 cub. centims. contain 0.945 gram of potassic hyposulphite.

200 cub. centims., evaporated with concentrated sulphuric acid, gave 1.069 grams of potassic sulphate, containing 0.4793 gram of potassium, or in 1081 cub. centims. 2.590 grams of potassium.

From these data we find the following composition for the solution:

	Composition of original solution.	Composition according to analysis.
Potassic carbonate . .	1.650	1.521
" sulphate . .	1.188	1.589
" sulphide . .	2.534 $\begin{cases} S = 1.4366 \\ K = 1.0977 \end{cases}$	1.633 $\begin{cases} S = 0.925 \\ K = 0.708 \end{cases}$
" hyposulphite .	0.114 $\begin{cases} S = 0.0384 \\ K = 0.0468 \end{cases}$	0.945 $\begin{cases} S = 0.318 \\ K = 0.387 \end{cases}$
Potassium	2.609	2.590

The mixture of cupric oxide and sulphide, dissolved in concentrated nitric acid yielded 8.16 grams of baric sulphate, corresponding to 1.120 grams of sulphur.

	Sulphur. Contained in original solution	Sulphur. Found by analysis.
Potassic sulphate	0.2180	0.291
" sulphide	1.4366	. .
" hyposulphite	0.0384	0.318
" Cupric oxide	0.0000	1.120
	1.693	1.729

From these experiments we conclude that by treatment of a solution containing potassic tersulphide, carbonate, and sulphate with cupric oxide, not only potassic hyposulphite, but also potassic sulphate is formed.

Experiments with Potassic Monosulphide.

A solution of 5 grams of pure potassic hydrate, in 100 cub. centims. of water, was divided into two equal parts; one of these was saturated with sulphuretted hydrogen and then mixed with the other.

20 cub. centims. of this solution gave, after evaporation with hydric chloride, 1.1015 grams of neutral potassic chloride, corresponding to 0.812 gram of potassic monosulphide (K_2S).

20 cub. centims. of the solution of the monosulphide were mixed with 2.219 grams of potassic carbonate and 0.950 gram of sulphate, and the mixture digested with pure cupric oxide at common temperatures, in a stoppered bottle, until all the potassic sulphide had been decomposed.

The contents of the bottle were treated in the same manner as in former experiments.

The filtrate of the cupric oxide measured 415 cub. centims.

160 cub. centims. required 2.1 cub. centims. of the iodine solution; therefore we have, in 415 cub. centims. of the filtrate, 0.103 gram of potassic hyposulphite.

It was ascertained, by special experiment, that the original potassic monosulphide did not contain hyposulphite.

60 cub. centims. of the liquid gave 0.185 gram of baric sulphate, corresponding to 0.953 gram of potassic sulphate in 415 cub. centims. of the filtrate.

100 cub. centims. gave with manganous sulphate a precipitate from which 0.174 gram of carbonic acid and 0.428 gram of Mn_3O_4 were obtained. It follows from these numbers that 415 cub. centims. of filtrate contain 0.758 gram of monosulphide and 2.261 grams of carbonate of potassium.

40 cub. centims. of the filtrate evaporated with hydric chloride, and the remaining potassic chloride converted by means of hydric sulphate into potassic sulphate, gave 0.482 gram neutral potassic sulphate. Hence, 415 cub. centims. contain 2.238 grams of potassium.

From the solution of the cupric oxide and sulphide in concentrated hydric nitrate, 1.684 grams of baric sulphate were precipitated; 1.684 grams of baric sulphate contain 0.231 gram of sulphur.

	Composition of original substance.		Found by analysis.	
Potassic carbonate, . . .	2.219		2.261	
" sulphate, . . .	0.950		0.953	
" monosulphide, .	0.812	$K = 0.5765$ $S = 0.236$	0.758	$K = 0.538$ $S = 0.220$
" hyposulphite, .	0.000		0.103	$S = 0.034$
Potassium, ...	2.255		2.238	
Sulphur in cupric oxide, .	0.000		0.231	

From these experiments it follows, as a general result, that if a solution containing potassic sulphate, carbonate and mono- ter- or pentasulphide of potassium is digested with pure cupric oxide, the determination of the potassic carbonate yields in all cases a nearly correct result; also for the sulphate an accurate value is obtained in a solution which contains the sulphide as monosulphide, but the numbers found for potassic sulphides are always incorrect. The potas-

sium hyposulphite is formed by the action of cupric oxide upon pentasulphide of potassium in such quantities that a convenient method for the preparation of the salt might be based on the reaction.

Probably all the potassic hyposulphite which was found in powder residues by Bunsen and Schischkoff's method of analysis, was formed during the analytical operations by the oxidation of potassic sulphide by the oxygen of the cupric oxide. At all events, we cannot assume that potassic hyposulphite is one of the products of the explosion of gunpowder, because at 225° C. it decomposes, according to Pape, into potassic sulphate and pentasulphide, and because in later experiments, in which zinc chloride was used instead of cupric oxide, Noble and Abel found very little potassic hyposulphite. We are, therefore, justified in replacing the hyposulphite of the analyses of Noble and Abel by its equivalent quantity of potassic sulphide.

The values found by means of Bunsen and Schischkoff's method for the potassic sulphate would be correct if the powder residues contained only potassic monosulphide. But as, according to Linck's and Noble and Abel's experiments, they contain one of the higher sulphides, it is not improbable that a portion of the sulphate observed has been formed during the treatment with cupric oxide from one of the said sulphides, or by the decomposition of potassic hyposulphite during the process of analysis.

The following considerations indicate how this possible error can be corrected:

If powder is burnt in the apparatus of Noble and Abel, all the oxygen of the decomposed saltpetre is incorporated in the potassic carbonate and sulphate, the carbonic acid and oxide, and these, together with the potassic sulphide, nitrogen and free sulphur amount to about 96 per cent. of the exploded powder. The following calculation leads to the conclusion that the oxygen of the charcoal and of the moisture in the powder does not enter into the composition of the principal products of explosion, but is eliminated in union with hydrogen in the form of water.

According to analysis, the composition of the F. G. powder is represented by the symbols

$$16KNO_3+0.044K_2SO_4+6.88S+20.81C+10.78H+3.52O$$

if ash and moisture of the charcoal are left out of consideration. In Experiment 17 of Noble and Abel the hydrogen in ammonic carbon-

ate, sulphuretted hydrogen, and in a free state, added together is equal to 4.1 atoms. This number deducted from 10.78 atoms, the hydrogen of the charcoal, leaves as difference 6.68 atoms. These 6.68 atoms of hydrogen must have formed water, for which operation 3.34 atoms of oxygen, or almost the exact quantity contained in the charcoal, is required.

Also the moisture of the powder cannot have contributed any oxygen, because if it had, an equivalent quantity of hydrogen ought to have been set free, or entered into combination with nitrogen, carbon, or sulphur. And as in all other experiments of Noble and Abel, executed with F. G. powder from Waltham Abbey, the number of atoms of hydrogen, free or combined, which occur amongst the products of combustion, is less than 4.1, it follows that in these other experiments also the oxygen of the charcoal or of the moisture of the powder has taken no part in the explosion. And finally, since several hundred grams of powder were exploded in a *hermetically* closed steel cylinder, oxygen from the atmosphere cannot have entered into the composition of products of combustion of the powder.

If, then, we find in one of the experiments, after the potassic hyposulphite has been replaced by its equivalent of potassic sulphide, that the sum of the quantities of oxygen contained in the potassic carbonate and sulphate, carbonic acid, and oxide exceeds the oxygen derived from the decomposed saltpetre, we may assume that this excess of oxygen is owing to some sulphate which had been formed during the process of analysis, and accordingly we shall be justified in deducting this excess of sulphate from the total quantity found.

The errors which have been explained on p. 12, due to the mode of calculation, will compensate each other, if the *mean of all the experimental results* be taken.

If all these corrections are carried out we obtain in the form of a chemical equation an approximately correct expression of the metamorphosis of the powders of Waltham Abbey. This equation, deduced from the 31 experiments published by Noble and Abel, is:

$$\left.\begin{array}{l} 4.98K_2CO_3 + 13.13CO_2 + 0.84S \\ + 0.90K_2SO_4 + 3.23CO \quad + 0.67H_2S \\ + 2.10K_2S_2 \quad + 17.34N \end{array}\right\} = \left\{\begin{array}{l} 16KNO_3 + 1.34N \\ + 21.35C + 1.34H \\ + 6.63S \end{array}\right\} \text{(I)}$$

The powder constituents on the right-hand side of the sign of equality have been calculated from the composition of the products of explosion.

The same constituents, as found by the direct analysis of the powders, are represented by the symbols:

$$16KNO_3 + 21.18C + 6.63S$$

which are in close agreement with those deduced from the products of explosion. Powder of this composition, burnt according to the method of Noble and Abel, will form the products of explosion in quantities as represented by equation (I), if the small quantities of secondary products arising from the presence of hydrogen in charcoal, such as marsh gas, ammonia, and free hydrogen, are neglected.

The sulphuretted hydrogen is either the product of the direct union of hydrogen and sulphur at comparatively low temperatures, or of the action of carbonic acid and water upon potassic sulphide. In either case its formation has no direct connection with the explosion, and it ought to be likewise omitted from an equation representing the metamorphosis of gunpowder.

0.84 atom of sulphur is represented as free, because there are no data to show how much sulphur has united with the iron of the apparatus.

It is usual to represent the potassic sulphide as monosulphide. Further on it will be shown that this is not correct, but that disulphide is really produced.

We may then replace equation (I) by the more simple one,

$$16KNO_3 + 21C + 5S = \left.\begin{array}{l} 5K_2CO_3 + 13CO_2 \\ 1K_2SO_4 + 3CO \\ 2K_2S_2 \quad + 8N_2 \end{array}\right\} \quad . \; . \; . \; . \; . \quad \text{(II)}$$

A portion of the sulphur of the powder has united with hydrogen and iron, hence the difference of sulphur in equations (I) and (II).

A powder consisting of

$$16KNO_3 + 21C + 5S$$

exploded according to the method of Noble and Abel in a vessel the substance of which is not attacked by the products of combustion ought, *cæteris paribus*, to yield the products of explosion always in the proportions represented in equation (II).

Under very great pressures the amount of carbonic oxide appears to diminish to a small extent; this variation of the carbonic oxide has, however, only a slight influence on the other products, amounting in the case of potassic carbonate, potassic sulphate, and potassic disulphide generally to less than 0.1 of a molecule. (See note, p. 4.)

Equation (II) expresses only the quantitative relations between the powder constituents and the products of explosion; the reactions which occur during explosion, which of them are simultaneous, and the order in which they succeed each other have still to be determined.

The solid products of explosion possess the composition and the properties of liver of sulphur prepared with an insufficient quantity of sulphur. We can conceive that, at first, all the potassium of the saltpetre forms with carbon and oxygen potassic carbonate, and that, in another stage, sulphur acts on the potassic carbonate and produces the mixture known as the solid powder residue. Or we may conceive that potassic sulphate is the first product, and that this is afterwards reduced by carbon to potassic disulphide and carbonate. Both conceptions would lead to the same results.

The experiments of Karolyi,* executed more than 17 years ago, contain the key to a chemical theory of gunpowder, and allow us to form an idea of the nature of the reactions, and the order in which they follow each other during the combustion of powder. He proposed to himself to decide by experiment whether or not the nature of the products and their relative quantities are dependent on the pressure which obtains during explosion. Craig † had asserted that under great pressure, such as would exist during the explosion in a piece of ordnance, much more potassic sulphide was formed than had been obtained by Bunsen and Schischkoff under ordinary atmospheric pressure. Karolyi took 36.836 grams of Austrian cannon powder, which had, according to his opinion, a composition similar to that of the powder employed by Bunsen and Schischkoff, and enclosed the same in a small metallic cylinder, suspended in the centre of a 60-pounder hermetically closed shell. The air was then pumped out of the shell by means of an air-pump, and the powder exploded by an electric current. As soon as the pressure of the gases in the cylinder had attained a certain magnitude the cylinder burst, and its contents were scattered about the space of the exhausted shell.

The capacity of the shell and the amount of powder had been so adjusted that after explosion the gases in the shell should possess a tension of about 1.5 atmospheres; they were allowed to escape into tubes and sealed up for analysis. The solid products, which were

* Pogg. Ann., Bd. cxviii, p. 544.

† Silliman's Am. J. [2], vol. xxxi, p. 429; Chem. News, vol. iv, p. 18.

removed from the shell by means of water, as well as the gases, were examined by the methods of Bunsen.

A similar experiment was made with 34.153 grams of rifle powder.

Composition of the Powders.

	Cannon powder.	Rifle powder.
Saltpetre	73.78	77.15
Sulphur	12.80	8.63
Charcoal—		
Carbon	10.88	11.78
Hydrogen	0.38	0.42
Oxygen	1.82	1.79
Ash	0.31	0.28

Composition of the Products of Explosion.

	Cannon powder. Grams.	Rifle powder. Grams.
Potassic carbonate	7.14	7.096
" sulphate	13.61	12.354
" hyposulphite	1.04	0.605
" sulphide	0.04	0.000
Carbonic acid	6.40	7.442
" oxide	0.97	0.504
Nitrogen	3.60	3.432
Hydrogen	0.04	0.047
Marsh gas	0.15	0.167
Sulphuretted hydrogen	0.10	0.079
Carbon	0.94	0.887
Sulphur	1.73	0.397
Ammonic carbonate	0.99	0.908
Loss	0.08	0 235

Cannon powder gave 30.77 per cent. of gas and 69.25 per cent. solid residue. Rifle powder gave 34.86 per cent. of gas and 65.14 per cent. solid residue.

Karolyi, comparing his results with those of Bunsen and Schischkoff, arrives at the conclusion that the nature and quantities of the products of explosion are not much influenced by the conditions under which the combustion takes p ace, but that the composition of the powder determines in a great measure the proportions in which the products of explosion are formed. Besides this, he deduces no

other conclusions from his experiments. Karolyi's observations do not support Craig's assertion; the pressure in the metallic cylinder before explosion must have been great, yet very little or no potassic sulphide has been formed.

A few years later (1869) Fedorow* published the results of some experiments executed by him on the explosion of gunpowder. He, like Craig, concludes that under high pressure more potassic sulphide is produced than would be formed by the same powder under lower pressures.

The experiments of Fedorow, however, do not prove anything of the kind. He fired powder from a pistol and from a 9-pounder cannon, and it appears that the solid products of the powder fired from the pistol were collected in a glass tube. A charge of 0.75 gram of powder gave a residue with proportionally more potassic sulphate and less of potassic sulphide than one of 1.5 grams, and relatively still smaller was the potassic sulphate and greater the sulphide in the residue obtained by the firing of 3 lbs. of powder from the cannon.

M. Fedorow concludes: A smaller amount of powder remains unconsumed, less potassic sulphate, but more sulphide and carbonate are formed under higher than under lower pressures. Time acts like pressure. If the combustion of the powder is retarded the same effects follow as if the pressure had been increased. A charge of 1.5 grams of a mixture consisting of 100 parts of meal powder, and 0.5 part of stearic acid, gave a residue with less potassic sulphate, but with more carbonate and hyposulphite than a similar charge of ordinary powder would have done.

Potassic sulphide is, as is well known, a substance endowed with great attraction for oxygen, not only at high, but also at ordinary temperatures. It appears that the air was not excluded from the glass tube into which M. Fedorow fired his charges for the collection of the solid residues. A greater percentage of the potassium sulphide formed by a small charge, than of the sulphide of the products of a larger charge will in this manner be oxidized.

It thus appears that M. Fedorow's experiments can be explained without reference to pressure. But as far as the retardation of the combustion by stearic acid is concerned, we cannot ascribe to retard-

*Zeitschrift für analytische Chemie, Bd. ix., p. 127; Strecker, Jahresbericht, 1869, p. 1059.

ation an effect which is due to the stearic acid itself. Stearic acid at a red heat reduces potassic sulphate to sulphide and probably carbonate.

M. Fedorow could not collect and examine the gases.

The experiments of Fedorow do not establish a relation between pressure and the nature and quantities of the products of explosion, and, consequently, do not invalidate the conclusions of Karolyi, as stated on pp. 26 and 27.

We will now proceed to explain, by means of the analytical results of Karolyi, some of the reactions which take place during the combustion of gunpowder. For this purpose it will be desirable to express the composition of the Austrian powders, and the products of explosion, by chemical formulæ.

Composition of the Powders.

	Cannon Powder.	Rifle Powder.
Saltpetre	16.00 mols.	16.00 mols.
Sulphur	8.70 atoms.	5.66 atoms.
Carbon	19.80 "	20.57 "
Hydrogen	8.32 "	8.80 "
Oxygen	2.50 "	2.34 "

Composition of the Products of Combustion of Quantities of Powder which contain 16 mols. of Saltpetre.

	Cannon Powder.	Rifle Powder.
Potassic carbonate	3.05 mols.	3.27 mols.
" sulphate	4.61 "	4.52 "
" hyposulphite	0.31 "	0.20 "
" sulphide	0.01 "	0.00 "
Carbonic acid*	9.23 "	11.46 "
" oxide	2.04 "	1.15 "
Nitrogen	7.55 "	8.06 "
Sulphuretted hydrogen	0.17 "	0.14 "
Hydrogen	2.36 atoms.	3.01 atoms.
Marsh gas	0.55 mol.	0.67 mol.
Ammonia	0.92 "	0.91 "
Carbon	4.61 atoms.	4.74 atoms.
Sulphur	3.16 "	0.79 "

* Inclusive of the carbonic acid combined with ammonia.

Calculated from the products of combustion, we obtain for

Cannon powder . . . $16KNO_3 + \underbrace{19.48C + 7.66H}_{\text{Charcoal.}} + 8.58S$

Rifle powder . . . . $16KNO_3 + \underbrace{21.4C + 8.7H}_{\text{Charcoal.}} + 5.68S + 1.04N.$

The potassic carbonate, potassic sulphate, potassic hyposulphite, and potassic sulphide, the nitrogen, carbonic acid, and carbonic oxide added together, amount in the case of the cannon powder to 89.6, and in that of the rifle powder to 92.0 per cent. of the exploded powder. 7.2 per cent of carbon and sulphur of the cannon powder and 3.7 per cent. of the same elements of the rifle powder, remained free at the end of the explosion. The sum of all the other products, therefore, does not amount to more than 3 or 4 per cent., and as, with the exception of the nitrogen in the ammonia, no constituents of the saltpetre occur in them, they may be regarded as merely accessory products not directly concerned in the explosion.

As the composition of the Austrian service powders does not differ much from that of the powders of Waltham Abbey, it will be interesting to contrast the results of Karolyi with those obtained by Noble and Abel.

Remarkable differences will be observed if equation (I), page 23, is compared with the composition of the products of combustion observed by Karolyi and represented by means of chemical symbols as above. Equation (I), as well as Karolyi's results, are calculated for quantities of powder containing 16 mols. KNO_3.

Noble and Abel, according to equation (I), found about a quarter of the potassium of the decomposed saltpetre as potassic sulphide, whereas in Karolyi's experiments the sum of the potassium in the hyposulphite, and in the sulphide of the products of combustion of cannon powder amounted to only $\frac{1}{2}$ th, and in that of the rifle powder only to $\frac{1}{40}$th of the potassium of the saltpetre of the exploded powder. It seems to follow that the production of such small quantities of potassic hyposulphite and sulphide cannot be the direct result of the chief reactions of the explosion. Karolyi obtained much more potassic sulphate and less potassic carbonate than the English chemists; a considerable quantity of the carbon of his powders remained unconsumed, whilst in Noble and Abel's experiments, as a rule, every trace of this element was burnt, although the English

powders contain somewhat more carbon than the Austrian. Similar differences occur between the results obtained with the gaseous products. The gases obtained by Karolyi were combustible, those of Noble and Abel were not. The gases from the Austrian powders contained more hydrogen and marsh gas and less sulphuretted hydrogen than those from the mixtures of Waltham Abbey.

	Mean percentage by volume. Austrian.	Waltham Abbey.
Hydrogen	6.41	2.50
Marsh gas	2.86	0.31
Sulphuretted hydrogen . . .	0.76	2.56

Karolyi inclosed his powders in a thin brass cylinder hermetically closed, and ignited the charge by means of a galvanic current. As soon as the tension of the gases developed by the combustion had reached a certain magnitude the metal cylinder exploded, and its contents were scattered against the cold sides of the exhausted 60-pounder shell. Thus the combustion of the powder was interrupted before its completion. The correctness of this view is rendered apparent if the effect is considered which would have followed if the products of Karolyi had remained in contact for some time at a red heat. The free carbon and hydrogen, and the constituents of the marsh gas would have been burnt at the expense of the oxygen of the potassic sulphate; the quantity of the latter would have been diminished and that of the sulphide increased, the free sulphur would have decomposed potassic carbonate with production of potassic sulphate and sulphide; in short, the products of combustion would have formed in similar proportions as we find them in Noble and Abel's experiments. The products of several hundred grams of powder remained in a fluid condition at a white heat in Noble and Abel's steel cylinder from 60 to 100 seconds in contact, whereas the 36 grams of burning powder were scattered after the explosion of Karolyi's brass cylinders over the cold sides of a large iron shell, and their combustion occupied only a very small fraction of a second. The reactions between the powder constituents had time to complete themselves in Noble and Abel's steel cylinder, but they had not in Karolyi's small brass vessel. And although the time of the combustion in the experiments of the last-named chemist was very short, less than one second, we find all the saltpetre of the powder decomposed and its constituents incorporated in the potassium salts, carbonic oxide and carbonic acid, or set free as nitrogen.

At the same time two of the potassium salts, the hyposulphite and sulphide, occur in such small quantities that we may regard them as secondary products, not connected with the chief reactions of the explosion, and accordingly neglect them.

Hence we have, as chief products formed in Karolyi's experiments: potassic sulphate and potassic carbonate, carbonic acid and nitrogen, and perhaps carbonic oxide.

The combustion of gunpowder accordingly consists of two distinct stages; a process of oxidation, which is finished in a very short time, occupying only a very small fraction of a second, and causing the explosion, and during which potassium carbonate and sulphate, carbonic acid, some carbonic oxide and nitrogen are produced, and a process of reduction, which succeeds the process of oxidation and requires a comparatively long time for its completion. As the oxygen of the saltpetre is not sufficient to oxidize all the carbon to carbonic, and all the sulphur to sulphuric acid, a portion of the carbon and a portion of the sulphur are left free at the end of the process of oxidation. The carbon so left free reduces, during the second stage of the combustion, potassic sulphate, and the free sulphur decomposes potassic carbonate. Hydrogen and marsh gas, which are formed by the action of heat upon charcoal, likewise reduce potassic sulphate, and some hydrogen combines with sulphur, forming sulphuretted hydrogen.

Great variations of pressure appear to affect the proportions of the different products in a very slight degree, so that it may be regarded as doubtful whether pressure has any influence on them.

Karolyi's experiments happen to be arranged in such a manner that the combustion of his powders could only proceed to the end of the first and the commencement of the second stage; in Noble and Abel's explosions, the reactions of the second stage were also completed.

This view of the combustion of gunpowder explains not only the experiments of Noble, Abel, and Karolyi, but is also in perfect accordance with the thermo-chemical relations of the products of explosion.

The heat of formation of a molecule of potassic sulphate is much greater than that of one of potassic sulphide, hence the production of the former is to be expected during explosion. In short, the formation of the molecules of potassic carbonate, potassic sulphate, and carbonic acid is accompanied by the greatest evolution of heat.

Karolyi examined the products of explosion according to Bunsen and Schischkoff's method, which does not yield exact values for

potassic sulphide and sulphate. The errors arising from this source will, however, be very small, if the potassic sulphide in the original powder residue is small. The small amount of potassic hyposulphite found by Karolyi proves that the products of combustion contained, in his experiments, very little potassic sulphide. As the potassic hyposulphite must be regarded as a product of oxidation of the potassic sulphide, it has been replaced in the following calculations by its equivalent of potassic sulphide. Nevertheless, the quantity of the latter does not exceed 0.32 of a molecule, hence the error caused by the method of analysis may be neglected.

We will now take the chief products of explosion observed by Karolyi, and calculate from their composition the quantities of powder constituents which took part in their formation, and arrange the results in form of equations.

CANNON POWDER.

$$\left.\begin{array}{l} 3.05\ K_2CO_3 \\ 4.62\ K_2SO_4 \\ 0.33\ K_2S_2 \\ 9.23\ CO_2 \\ 2.04\ CO \\ 7.55\ N_2 \end{array}\right\} = \left\{\begin{array}{ll} 16 & KNO_3 \\ 14.32 & C \\ 5.28 & S \\ -0.9 & N \\ 0.13 & O \end{array}\right.$$

RIFLE POWDER.

$$\left.\begin{array}{l} 3.30\ K_2CO_3 \\ 449\ K_2SO_4 \\ 0.20\ K_2S_2 \\ 11.49\ CO_2 \\ 1.15\ CO \\ 8.00\ N_2 \end{array}\right\} = \left\{\begin{array}{ll} 16 & KNO_3 \\ 15.94 & C \\ 4.89 & S \\ 3.99 & O \end{array}\right.$$

The entire quantity of saltpetre contained in the powders taken for these experiments was decomposed, and its constituents, with the exception of very small quantities of potassium and nitrogen, in potassic sulphocyan te and ammonia, reappear in the above chief products. The cannon powder contains for every 16 mols. of KNO_3 about 3 atoms of sulphur more than the rifle powder (p. 29). Nevertheless, during the first stage of the combustion the quantities of sulphur consumed in the formation of potassic sulphate are nearly the same in the experiments with both powders, and the potassic carbonate and disulphide are also almost identical.

The ratios of the oxygen in the potassic carbonate, sulphate, and carbonic acid are as follows:

	Oxygen.		
	K_2CO_3	K_2SO_4	CO_2
Cannon powder .	9.15	18.44	18.46
	1	2	2
Rifle powder . .	9.90	17.96	22.98
	1	1.81	2.33

The amount of oxygen in the products of explosion of the rifle powder has been found about 1.2 per cent. too high, consequently an error attaches to one or more of the analytical determinations.

The metamorphosis of the cannon powder during the first stage of the combustion can almost exactly, that of the rifle powder approximately, be represented by the equation

$$10(KNO_3)+8C+3S=2(K_2CO_3)+3K_2SO_4)+6(CO_2)+5(N_2) \quad \text{(III)}$$

It is worthy of notice that the ratios of the oxygen in the three principal products, potassic carbonate, potassic sulphate, and carbonic acid, are, according to equation (III), of all possible ratios the most simple, if these products are to be formed by the combustion of a mixture of saltpetre, carbon and sulphur.

From these considerations it appears to follow that during the explosion of gunpowder, or the first stage of its combustion, the constituents of powders which differ in their composition will act on each other in certain fixed stoichiometrical proportions.

It may be assumed as highly probable that of the infinite number of mixtures which can be prepared from saltpetre, carbon, and sulphur, some will be more combustible than others, and, among the more combustible mixtures, one will be found containing the constituents in proportions most favorable for their transformation into the chief products of explosion. In this most combustible mixture the number of the molecules of saltpetre and of the atoms of carbon and sulphur will probably stand in simple arithmetical relations to each other, and if a mixture containing the constituents in other proportions be ignited, they will tend to react on each other in the stoichiometrical proportions of the most combustible mixture.

Equation (III) can be transformed into:

$$16KNO_3 + 12.8C + 4.8S = 3.2K_2CO_3 + 4.8K_2SO_4 + 9.6CO_2 + 8N_2$$

and as during the first stage of the combustion some carbonic oxide is probably also formed, we may write the equation instead

$$16KNO_3+13C+5S = 3K_2CO_3+5K_2SO_4+9CO_2+CO+8N_2 \quad \text{(IV)}$$

This equation explains the experiments of Karolyi in a very satisfactory manner.

If the reactions went a little beyond the first stage of the combustion, and we add to the left of the sign of equality 1.32 atoms of carbon, which would reduce some potassic sulphate with formation of potassic sulphide and carbonate, carbonic acid and oxide, according

to equations which will be given afterwards, numbers are obtained which are almost identical with those calculated from Karolyi's observations on the products of explosion of cannon powder (p. 32). The same remark applies to the products of the rifle powder, except the carbonic acid.

The excess of oxygen found in the products of rifle powder indicates that some error has occurred in the determinations of these products, and it seems to have influenced, almost exclusively, the carbonic acid. If the quantity of this substance is calculated according to the available oxygen of the decomposed saltpetre, a number is obtained which agrees very well with equation (IV).

From the foregoing observations it follows that powders of the composition of the Austrian service powders—

$$16KNO_3 + 19.8C + 8.7S$$
$$\text{and} \quad 16KNO_3 + 20.57C + 5.66S$$

burn during the first stage of the metamorphosis according to the equation:

$$16KNO_3 + 13C + 5S = 3K_2CO_3 + 5K_2SO_4 + 9CO_2 + CO + 8N_2$$

and that the carbon and sulphur which the powders contain, beyond the quantities required by this equation, remain free.

The very combustible sporting powder of Bunsen and Schischkoff contained

$$16KNO_3 + 13.3C + 6.3S$$

Therefore, it will be seen that the constituents of the service powders react upon each other during the first stage of the explosion nearly in the same stoichiometrical quantities in which they are contained in the more highly combustible sporting powder.

If it be correct that equation (IV) represents proportions of saltpetre, carbon, and sulphur, in which these substances will burn with greater facility than they do in the proportions of the service powders, then we can by means of equation (IV) calculate the composition of a powder which shall be distinguished by its great combustibility.

Besides saltpetre, carbon and sulphur, hydrogen, oxygen, ash, and moisture are contained in gunpowder. The weight of these latter constituents is about 4 per cent. of the mixture. If we add 4 per cent. to the quantities represented by the symbols

$$16KNO_3 + 13C + 5S$$

and consider hydrogen, oxygen, ash, and moisture united with carbon to charcoal, we obtain for the percentage composition of the most combustible mixture

Saltpetre	80.31
Sulphur	7.95
Charcoal	11.74

Sporting powders are required to burn quickly, and the composition of some of them approaches very closely to these theoretical values.

	Saltpetre.	Sulphur.	Charcoal.
English *	79.7	7.8	12.5
French, ...	78.0	10.0	12.0
Bunsen and Schischkoff's powder, .	78.99	9.84	11.17
Sporting powder in the year 1546, .	83.4	8.3	8.3

The heat relations of the products of explosion, as represented by equation

$$16KNO_3 + 13C + 5S = 3K_2CO_3 + 5K_2SO_4 + 9CO_2 + CO + 8N_2,$$

are of special interest.

If we assume for the heat of formation of potassic carbonate, potassic sulphate, and carbonic acid the following values:

$$K_2CO_3 = 279540 \text{ cal.}$$
$$K_2SO_4 = 344640 \text{ "}$$
$$CO_2 = 97000 \text{ "}$$

we obtain

$$3 \times 279540 = 838620$$
$$5 \times 344640 = 1723200$$
$$9 \times 97000 = 873000$$
$$838620 : 1723200 : 873000 = 1 : 2.05 : 1.04$$
$$\text{or nearly } 1 : 2 : 1$$

ratios which are very remarkable.

The total amount of heat produced by the combustion of $16KNO_3 + 13C + 5S$ according to equation (IV), is $= 1563189$ cal. The maximum amount of heat is produced by a mixture which contains for every 16 mols. of saltpetre 8 atoms of carbon and 8 atoms of sulphur, according to the equation

$$16KNO_3 + 8C + 8S = 8K_2SO_4 + 8CO_2 + 8N_2$$

and amounts to 1621450 cal.

* Graham-Otto, "Lehrbuch der Chemie," iv edit., ii, p. 211.

Therefore, if the combustion of ordinary service powder takes place during the first stage according to equation (IV), nearly the maximum quantity of heat is obtained which a mixture of saltpetre, sulphur, and carbon can produce. If the question were asked: in what proportions must the constituents of a given mixture of saltpetre, carbon, and sulphur react during the process of explosion, and what must be the ratios of the chief products of explosion, so that on one hand the total quantity of heat developed is as great as possible, and, on the other hand, the amounts of heat produced by the formation of the chief products shall stand to each other in a simple relation? the answer would be: the combustion must take place according to equation (IV).

But not only does this equation correspond to the most simple relations of the heat of formation of the principal products, it likewise requires the most simple distribution of the oxygen of the decomposed saltpetre. If the combustion of a mixture of saltpetre, carbon, and sulphur is to produce potassic carbonate and sulphate, carbonic acid and nitrogen, and if the oxygen of each of the first three products is to stand to the oxygen of the others in the most simple ratios possible, then the mixture must burn according to equation (III), p. 33, and as the proportions expressed by equation (IV) closely approach to those of equation (III), it follows that equation (IV) fulfils all the conditions and consequences explained in the foregoing lines. And, perhaps, these relations are the cause why mixtures of saltpetre, carbon, and sulphur of different composition burn during the first stage of the explosion according to equation (IV), and if they contain more carbon and sulphur than is required by this equation, the excess of the two elements will remain free.

These interesting conclusions I deduce from the analytical data of Karolyi and the corrected results of Noble and Abel's experiments. Their investigations, however, do not give any information about the reactions of the second stage of the combustion of gunpowder, the reduction of potassic sulphate by carbon, and the decomposition of potassic carbonate by sulphur. Hitherto it has been assumed that potassic mono-sulphide is formed; this is, however, a mistake.

According to Berzelius and Mitscherlich,* the products of the decomposition of potassic carbonate by sulphur at a white heat are potassic sulphate and disulphide:

$$4K_2CO_3 + 7S = K_2SO_4 + 3K_2S_2 + 4CO_2$$

* Gmelin-Kraut, "Handbuch der Chemie," Bd. ii, p. 39.

The question we have now to solve is: which of the sulphides of potassium is formed by the action of carbon upon potassic sulphate at a white heat?

Bauer* and Wittstock† obtained potassic carbonate and a polysulphide, but the amount of sulphur in the polysulphide was not determined.

A mixture of

26.5 grams of potassic sulphate
10.54 " " carbonate
2.5 " charcoal

was exposed in a porcelain crucible for half an hour to a temperature approaching white heat. The contents of the crucible dissolved completely in water, forming a deep yellow solution.

20 cub. centims. of this solution acidulated with hydric chloride, gave a copious precipitate of sulphur, and the filtrate of this precipitate left, after evaporation and treatment with hydric sulphate, 2.943 grams of potassic sulphate. The potassium of

1.960 grams potassic sulphate
0.779 " " carbonate

of the salts originally taken, is, accordingly, present in 20 cub. centims. of the solution.

20 cub. centims. of the solution gave by the usual method 1.038 grams of baric sulphate, corresponding to 0.775 gram of potassic sulphate.

19.28 cub. centims. of the same solution placed for some days in contact with 5 grams of cupric oxide and the carbonic acid in the liquid determined according to Bunsen's method gave 0.37 gram of this substance, which corresponds to 1.203 grams of potassic carbonate in 20 cub. centims. of the solution.

1.96 grams of potassic sulphate originally taken contain 0.36 gram of sulphur.

0.775 gram of potassic sulphate found in 20 cub. centims. contains 0.142 gram of sulphur.

Sulphur in potassic sulphide = 0.218 gram.

20 cub. centims. of the solution contain 1.318 grams of potassium.

1.203 grams of potassic carbonate contain 0.680 gram of potassium, and 0.775 gram of potassic sulphate 0.347 gram of potassium; the

* Gmelin-Kraut, "Handbuch der Chemie," Bd. ii, p. 33. † *Ibid.*, p. 33.

difference of 0.291 gram represents the potassium in potassic sulphide.

Hence the potassic sulphide produced by the action of the carbon of the charcoal upon the mixture of potassic sulphate and carbonate contains:

	Gram.
Potassium	0.291
Sulphur	0.218
	0.509

and the composition of the salts in 20 cub. centims. of the solution of the fused mass is:

	Found.	Taken.
Potassic sulphate	0.775	1.960
" carbonate	1.203	0.779
" sulphide	0.509	0.000

The composition of the potassic sulphide can be represented by the symbols

$$K_2S_{1.82}$$

Therefore, potassic sulphate and the carbon of charcoal react, under the conditions of the experiment, principally according to the equation

$$4K_2SO_4 + 7C = 2K_2CO_3 + 2K_2S_2 + 5\,CO_2.$$

Noble and Abel calculate their potassic sulphide as monosulphide, and in a special column give, as free sulphur, the sulphur not contained in the monosulphide, potassic sulphate and potassic hyposulphite. This so-called free sulphur was in reality contained in the residues partly in union with potassium as disulphide, partly with iron as ferrous sulphide.

If we imagine their free sulphur all combined with their potassic monosulphide, we obtain:

In 15 experiments united to two atoms of potassium, from 1.7 to 2.44 atoms of sulphur.

In seven experiments from 2.44 to 3.00 atoms of sulphur.

And in three experiments from 3.0 to 3.7 atoms of sulphur. The mean of 25 experiments would give us for 2 atoms of potassium 2.42 atoms of sulphur. But as a portion of the so-called free sulphur was in union with iron, it follows that in the powder residues 2 atoms of potassium were on an average combined with less than 2.42 atoms of

sulphur. These numbers, however, apply only to their corrected results.

According to Berzelius and Mitscherlich the action of sulphur upon potassic carbonate at a white heat produces K_2S_2; the reduction of potassic sulphate in presence of carbonate, according to my own experiments, gives $K_2S_{1.82}$; the mean of Noble and Abel's experiments for the composition of the potassic sulphide formed by the explosion of powder in their apparatus is less than 2.42 atoms of sulphur for every 2 atoms of potassium, hence we may conclude that the potassium sulphide formed during the second stage of the combustion of gunpowder is the disulphide, or at least contains the two elements in a proportion closely approaching the proportion in the disulphide. The following considerations confirm this conclusion.

The mean composition of the English service powder is:

$$16KNO_3 + 21.18C + 6.63S.$$

The Austrian rifle powder contains:

$$16KNO_3 + 20.57C + 5.66S$$

The products of combustion of the former are, according to Noble and Abel,

$$4.98K_2CO_3 + 0.90K_2SO_4 + 2.10K_2S + 13.13CO_2 + 3.23CO + 0.84S.$$

Those of the Austrian rifle powder, according to Karolyi, are

$$3.27K_2CO_3 + 4.52K_2SO_4 + 0.2K_2S_2 + 11.46CO_2 + 1.15CO + 4.74C + 0.79S.$$

Karolyi's products contain a considerable amount of free carbon, which element is completely burnt in Noble and Abel's experiments.

If we now assume that Karolyi's products had remained in contact at a high temperature, not a fraction of a second, but from one to two minutes, as was the case in Noble and Abel's experiments, the free carbon would have been oxidized by oxygen contained in potassic sulphate, and the free sulphur would have reacted upon the potassium carbonate, and the final result of these reactions would have been a quantitative relationship between the products similar to that found by Noble and Abel. The potassic carbonate, the potassic disulphide, the carbonic oxide, and carbonic acid would have increased, and the quantity of the potassic sulphate would have diminished. But the

amount of potassic carbonate could not become greater if the reduction of the sulphate took place according to the equation:

$$K_2SO_4+2C=K_2S+2CO_2$$

hence, we must assume the formation of potassic disulphide. If we calculate from the analytical data of Karolyi the proportions of his products on the supposition that the carbon which had remained free had acted on potassic sulphate according to the equation:

$$4K_2SO_4+7C=2K_2CO_3+2K_2S_2+5CO_2$$

we obtain:

$$4.65K_2CO_3+1.12K_2SO_4+2.22K_2S_2+14.08CO_2+2.65CO$$

quantities which are as near those found for the English powders as the composition of the Austrian rifle powder approaches those of Waltham Abbey.

If the potassic hyposulphite found by Bunsen and Schischkoff originated during the analysis of their powder residue, then the latter contained, for 16 mols. of decomposed saltpetre, 0.45 mol. of K_2S_2 and 0.33 mol. of K_2S.

Linck* found, amongst the products of the Würtemberg service powder, only potassic disulphide.

From Noble and Abel's† analysis of the products of English mining powder it would follow that for every 16 mols. of decomposed saltpetre, 4 mols. of K_2S are formed and 5 atoms of sulphur left free; this would give us for the composition of the potassic sulphide 2 atoms of potassium and 2.25 atoms of sulphur.

From these facts we conclude that the second stage of the combustion of gunpowder takes place according to the equations:

$$4K_2CO_3+7S=K_2SO_4+3K_2S_2+4CO_2 \quad . \quad . \quad . \quad . \quad (V)$$
$$4K_2SO_4+7C=2K_2CO_3+2K_2S_2+5CO_2 \quad . \quad . \quad . \quad . \quad (VI)$$

The possibility of dissociation requires the additional equation

$$K_2CO_3+K_2S_2+O_7=2K_2SO_4+CO_2 \quad . \quad . \quad . \quad . \quad (VII)$$

The final results of the reactions represented by equations (III), (IV), (V), (VI) and (VII) can be expressed by one equation.

For this purpose let x, y and z be positive numbers, and a denote how many molecules of carbonic oxide are formed by the combustion

* Ann. der Chemie und Pharm., Bd. cix. (1859), p. 53.

† Phil. Trans. (1880), p. 207.

of a quantity of powder containing x molecules of saltpetre, y atoms of carbon and z atoms of sulphur. The general equation representing the qualitative and quantitative relations between the constituents of a mixture of saltpetre, carbon and sulphur on the one hand, and the products of *complete* combustion on the other, will then be:

$$\left.\begin{aligned} xKNO_3+yC+zS = {} & \tfrac{1}{28}[4x+8y-16z-4a](K_2CO_3) \\ & +\tfrac{1}{28}[20x-16y+4z+8a](K_2SO_4) \\ & +\tfrac{1}{28}[-10x+8y+12z-4a](K_2S_2) \\ & +\tfrac{1}{28}[-4x+20y+16z-24a](CO_2) \\ & +\tfrac{1}{2}xN_2 \\ & +aCO \end{aligned}\right\} \quad \text{(VIII)}$$

As far as the application of this equation is concerned, the following remarks are, perhaps, not unnecessary.

The charcoal of gunpowder contains, besides carbon, also oxygen and hydrogen, ash and moisture. The oxygen of the charcoal is, as has already been proved before (pp. 22, 23), eliminated with some of the hydrogen as water. The rest of the hydrogen of the charcoal with nitrogen, carbon and sulphur respectively, forms by-products, the total weight of which, as a rule, does not exceed 2 per cent. of the powder burnt.

The products of combustion, with the exception of those prepared by Noble and Abel, contain always some unburnt carbon and sulphur, and frequently undecomposed saltpetre.

Hence we have:

a. Chief products: K_2CO_3, K_2SO_4, K_2S_2, CO_2, CO, and N_2.
b. By-products: H_2, H_2S, CH_4, NH_3, H_2O, and KCNS.
c. Constituents of powder, not burnt: KNO_3, C, and S.

Equation (VIII) enables us to calculate, from that portion of the powder which produces the chief products (mentioned under *a*), the quantities of these products formed during complete combustion.

We will now proceed to prove, by examples, the correctness of this equation.

Bunsen and Schischkoff found in 1 gram of sporting powder, and in the products of its combustion, the following quantities:

1 gram of powder—

Saltpetre	0.7899
Sulphur	0.0984

Charcoal—	
Carbon	0.0769
Hydrogen	0.0041
Oxygen	0.0307

Chief products of combustion—	
Potassic sulphate	0.4227
" carbonate	0.1264
" hyposulphite	0.0327
" sulphide	0.0213
Carbonic acid*	0.2159
" oxide	0.0094
Nitrogen	0.0998
	0.9282
By-products—	
Potassic sulphocyanate	0.0030
Hydrogen	0.0002
Sulphuretted hydrogen	0.0018
Oxygen	0.0014
Ammonia and water	0.0139
	0.0203

Powder constituents not decomposed or burnt—	
Saltpetre	0.0372
Carbon	0.0073
Sulphur	0.0014
	0.0459
Hence—	
Chief products	0.9282
By-products	0.0203
Unburnt powder	0.0459
	0.9944

If the potassic hyposulphite is replaced by its equivalent of potassic disulphide, the quantities of the chief products expressed in mole-

* Inclusive of the carbonic acid of the ammonic carbonate.

cular weights, and calculated for 16 mols. of decomposed saltpetre, we obtain:

$$1.97K_2CO_3+5.25K_2SO_4+0.45K_2S_2+10.59CO_2+7.7N_2+0.33K_2S+0.71CO.$$

From these symbols we calculate the following composition of the powder:

$$16KNO_3+13.2C+6.48S+0.66O.$$

If now we substitute, in equation (VIII), for x the number 16, for y 13.2, for z 6.5, and for a 0.71, we find for the chief products:

$$2.25K_2CO_3+5.01K_2SO_4+0.74+K_2S_2+10.25CO_2+0.70CO+8N_2$$

numbers which closely agree with those found by experiment.

The powder used by Bunsen and Schischkoff contains, according to analysis:

$$16KNO_3+13.3C+6.3S$$

a composition which is nearly the same as that deduced from the chief products of combustion.

The analytical method in this case causes no appreciable error in the determination of the potassic sulphate. Neither, according to my own analysis, does potassic monosulphide, nor, according to Noble and Abel's analysis of the residues of mining powder, does potassic disulphide produce potassic sulphate by treatment with cupric oxide. Bunsen and Schischkoff's residues contained a mixture of mono- and disulphide, and of both only a comparatively small quantity.

Linck* examined the products of combustion of the Würtemberg service powder according to the method employed by Bunsen and Schischkoff. He obtained the following results:

Composition of the powder—

Saltpetre	0.7470
Sulphur	0.1245
Charcoal—	
Carbon	0.0905
Hydrogen	0.0041
Oxygen	0.0278
Water	0.0060
	0.9999

* Ann. der Chemie und Pharm., Bd. cix., p. 53.

Chief products of combustion—

Potassic sulphate	0.2891
" carbonate	0.1537
" hyposulphite	0.0374
" disulphide	0.0959
Carbonic acid *	0.2345
" oxide	0.0118
Nitrogen	0.0952
	0.9176

By-products—

Potassic sulphocyanate	0.0116
Sulphuretted hydrogen	0.0238
Hydrogen	0.0003
Oxygen	0.0001
Ammonia and water	0.0098
	0.0456

Powder constituents not decomposed or burnt—

Saltpetre	0.0120
Carbon	0.0183
Sulphur	0.0031
	0.0334

Hence—

Chief products	0.9176
By-products	0.0456
Not burnt	0.0334
	0.9966

If we express the quantities of the chief products by means of molecular weights, and calculate how much of each would be formed by the combustion of a quantity of powder containing 16 mols. of saltpetre, we obtain:

$$2.43K_2CO_3 + 3.64K_2SO_4 + 0.43K_2S_2O_3 + 1.47K_2S_2 + 11.71CO_2 + 0.92CO + 14.94N$$

and expressed in powder constituents:

$$16KNO_3 + 15.06C + 7.44S - 1.06N - 0.52O.$$

* Inclusive of the carbonic acid in the ammonic carbonate.

The powder contained, according to analysis:

$$16KNO_3 + 16.3C + 8.4S.$$

The by-products contain no oxygen of the saltpetre, and with the exception of the potassium and nitrogen in the potassic sulpho-cyanate, and the nitrogen of the ammonia, their elements are derived from the charcoal and sulphur. The chief products should, accordingly, contain all the oxygen of the decomposed saltpetre. This, however, is not the case; 0.52 of an atom is wanting, and if the potassic hyposulphite, as we must assume, has been formed by the oxidizing action of the cupric oxide upon the potassic disulphide, then no less than 1.81 atoms or nearly $\frac{1}{26}$th of the oxygen of the decomposed saltpetre have disappeared. Linck himself finds in the products of combustion 1.75 per cent. or about $\frac{1}{22}$d less oxygen than in the original powder, and this loss of oxygen would have appeared still greater if he had not assumed that the oxygen of the hyposulphite had been derived from saltpetre. On the other hand, Linck finds in the products of explosion 0.71 per cent. or $\frac{1}{12}$th to $\frac{1}{13}$th more of carbon, and 0.9 or $\frac{1}{13}$th to $\frac{1}{14}$th more of sulphur than in the original powder. Accordingly, it follows, either that Linck's powder has not the composition which he ascribes to it, or that some considerable errors attach to the analytical data of the products of explosion. Hence, no near agreement can here be expected between theory and experiment.

If we replace the potassic hyposulphite found, by its equivalent of potassic disulphide, express the quantity of the chief products by molecular weights, and calculate the composition of that portion of the powder which was transformed into the chief products, we obtain

$$16KNO_3 + 15.06C + 7.44S - 1.06N - 1.81O.$$

and if in equation (VIII) we place,

$$x = 16 \qquad y = 15$$
$$z = 7.5 \qquad a = 1.0$$

we find the following theoretical values, which are placed by the side of the experimental numbers:

$$\left.\begin{array}{l} 16KNO_3 \\ 15C \\ 7.5S \end{array}\right\} = \left\{\begin{array}{lcc} & \text{Theory.} & \text{Experiments.} \\ K_2CO_3 \ \ldots & 2.14 & 2.43 \\ K_2SO_4 \ \ldots & 4.21 & 3.64 \\ K_2S_2 \ \ldots & 1.64 & 1.90 \\ CO_2 \ \ldots & 11.85 & 11.71 \\ CO \ \ldots & 1.0 & 0.92 \end{array}\right.$$

Some mistake appears to have occurred in the determination of the potassic sulphate and carbonate. The calculation could likewise be carried out in the following manner: The unburnt portion of the powder, and the quantities of the elements contained in the by-products, could be subtracted from the composition of the quantity of powder taken for experiment, and from the rest, the quantities of the products might be calculated according to the equation (VIII). This mode of calculation is in Linck's case not applicable, because large quantities of charcoal remained unburnt, the composition of which is not known. This charcoal having been exposed to the high temperature developed by the combustion of the powder can no longer have had the original composition, but was probably nearly pure carbon.

The composition of the Austrian cannon powder can be represented by the symbols:

$$16KNO_3+19.8C+8.7S$$

if hydrogen, oxygen, ash and moisture of the charcoal are neglected. All the potassium and the oxygen of the decomposed saltpetre reappeared in the chief products of explosion, but more than 4 atoms of carbon and 3 atoms of sulphur remained free. The amount of the sulphide formed by this powder was very small in Karolyi's experiment.

The powder constituents which were transformed into the chief products are represented by the symbols

$$16KNO_3+14.32C+5.28S$$

and 2.04 mols. of CO had been formed (p. 28).

The values of these coefficients substituted for x, y and z in equation (VIII) yield the following theoretical quantities of the chief products of combustion, to which are appended the quantities found by experiment:

		Theory.	Experiments.
$16KNO_3$, $14.32C$, $5.24S$ =	K_2CO_3	3.06	3.05
	K_2SO_4	4.59	4.61
	K_2S_2	0.33	0.33
	CO_2	9.12	9.23
	CO	2.04	2.04
	N_2	8.0	7.55

a striking confirmation of theory is thus presented.

The analysis of the products of explosion of rifle powder carried out by Karolyi is contaminated by a considerable error. He finds,

correctly, no oxygen in the by-products; but no less than 4 atoms or $\frac{1}{12}$th more oxygen appears in the chief products than in the decomposed saltpetre, and if from this the oxygen of the charcoal be subtracted there remain still 1.66 atoms of oxygen more than were contained in the entire powder. If these errors of experiment are corrected, by means of equation (VII), a very good agreement of the numbers calculated according to equation (VIII), and those derived from experiment, is obtained for rifle powder.

The mean composition of the powders of Waltham Abbey is expressed by the symbols

$$16KNO_3 + 21.18C + 6.63S$$

and because, during their combustion, 0.67 mol. of sulphuretted hydrogen is formed, there remain

$$16KNO_3 + 21.18C + 5.96S$$

for the formation of the principal products.

But as the portion of the sulphur which has united with the iron of the apparatus has not been determined by direct experiment, we are obliged to form an estimate of its amount from other considerations.

According to the remarks on pages 37–39, potassium disulphide is produced by the metamorphosis of gunpowder. The combustion of a quantity of powder containing 16 mols. of saltpetre produces, if we take the mean of all the experiments of Noble and Abel, 0.90 mol. of K_2SO_4 and 2.1 mols of K_2S_2, for which quantities 1 mol. of K_2SO_4 and 2 mols of K_2S_2 have been placed in equation (II). From this it follows that 5 atoms of sulphur have taken part in the metamorphosis, and that 0.96 atom of sulphur has remained free or has united with the iron of the explosion apparatus.

The experiments of Karolyi support this conclusion. The Austrian cannon powder containing 8.7 atoms, and the rifle powder 5.66 atoms of sulphur for every 16 mols. of saltpetre, and in the principal products of combustion of the former 5.25 atoms, and in those of the latter 4.89 atoms of this element were found, the rest of the sulphur having remained free. In spite of the great difference of the amounts of sulphur in the two descriptions of powders, we find in their products of combustion, for 16 mols. of decomposed saltpetre, almost the same quantity of sulphur, 5 atoms, in both cases. In Noble and Abel's experiments the sum of the sulphur in the sulphate and disulphide is likewise equal to 5 atoms. From this equality

we may conclude that in Noble and Abel's, as in Karolyi's experiments, during the first stage of combustion, or the stage of explosion, the powders were transformed according to equation (IV), page 33, and that 5 of the 5.96 atoms of sulphur entered into combination. The remaining 0.96S should, during the second stage, have reacted with potassic carbonate according to equation (V), page 40, but as this reaction appears not to have occurred, we may conclude, with great probability, that the 0.96 atom of sulphur united with the metal of the apparatus.

Since in Noble and Abel's experiments all the powder introduced into their apparatus was completely burnt, and as the sum of the weights of the secondary products, after deducting the sulphuretted hydrogen is very small, and finally, because potassium, oxygen and carbon in the principal products of combustion occur almost in the same proportions as in the saltpetre and charcoal of the original powder, we can substitute for x and y, in equation (VIII), the values derived directly from the composition of the powder.

If then we put in equation (VIII) $x = 16$, $y = 21.18$, $z = 5$, and for a, the carbonic oxide, the number 3.23, found by experiment, we obtain for the principal products values which in the following table have been placed by the side of those found by experiment:

		Theory.	Experiment.
$16KNO_3 + 21.18C + 5S =$	K_2CO_3	5.01	4.98
	K_2SO_4	0.96	0.90
	K_2S_2	2.01	2.10
	CO_2	12.93	13.13
	CO	3.23	3.23
	N_2	8.00	8.67

The theoretical numbers agree in a very satisfactory manner with those found by experiment.

According to what has been stated in these pages, we conceive the metamorphosis of gunpowder to take place in a shell, or in the bore of a gun, in the following manner. In the first moments after ignition, during the explosion, powders of different composition burn according to the equation

$$16KNO_3 + 13C + 5S = 3K_2CO_3 + 5K_2SO_4 + 9CO_2 + CO + 8N_2$$

and in case of a shell which will burst almost immediately and its contents be scattered about, no further changes take place.

In the bore of a gun the gases expand, move the shot, and by the performance of this work lose a portion of their energy; the products

of the first stage of the metamorphosis, potassic carbonate and potassic sulphate, remain at a red heat, in a fluid condition, for a longer time in contact with free carbon and sulphur, and produce, according to equations (V) and (VI), an additional quantity of carbonic acid. This carbonic acid, which is generated during the movement of the shot in the bore, prevents the too rapid diminution of the tension of the gases; the heat of the solid products is, in part, transformed into *vis viva* of the gas molecules. If the gun were long enough and the quantities of carbon and sulphur not too large, every atom of the former might be oxidized by the oxygen of the potassic sulphate, and the entire amount of the sulphur be converted into potassic disulphide and sulphate by contact with potassic carbonate. But in reality this second stage of the metamorphosis is perhaps never complete; the shot will have left the gun before the termination of these comparatively slow reactions.

The mining powders, strictly considered, do not belong to the category of gunpowders; they contain a large excess of carbon and sulphur. But as their metamorphosis clearly shows the source of the by-products of the combustion of gunpowder, we will discuss here the analytical data furnished by Noble and Abel of an experiment with a sample obtained from Curtis and Harvey.

Composition of the Powder.

	Saltpetre,	61.66
	Sulphur,	15.05
Charcoal	Carbon,	17.93
Charcoal	Hydrogen,	0.66
Charcoal	Oxygen,	2.23
	Water,	1.66
		99.19

which may be represented by the symbols:

$$16KNO_3 + 12.3S + \underbrace{39.18C + 16.16H + 3.65O}_{\text{Charcoal.}}$$

This mixture contains sulphur and carbon nearly in the same proportions as they occur in the service powder of Waltham Abbey [S : C = 1 : 3.21], and therefore differs by containing much less saltpetre.

The products of combustion, calculated for 16 mols. of decomposed saltpetre, yielded the following results:

$$\begin{array}{llll} 3.66K_2CO_3 + 13.47CO_2 + 2.96H_2S + 2C \\ +0.04K_2SO_4 + 14.10CO + 1.11CH_4 + 1.27S \\ +4.11K_2S_2 + 7.96N_2 + 2.2H_2 \\ +0.36KCNS \quad + 0.08[NH_4]_4H_2(CO_3)_3 \end{array}$$

from which we calculate the composition of the powder as follows:

$$16KNO_3 + 12.85S + \underbrace{34.94C + 16.2H + 4.42O}_{\text{Charcoal.}}$$

If we contrast the above results with those obtained by the explosion of the service powders of Waltham Abbey, (I), p. 23, it is seen that the large excess of carbon and sulphur in the mining powder has not diminished the amount of carbonic acid, but greatly increased the quantity of carbonic oxide. In the service powders, the oxygen of the charcoal is eliminated, with hydrogen, as water; in the mining powder it is found at the end of the combustion in union with carbon as carbonic oxide. The hydrogen of the charcoal thus set free partly remains so, partly unites with carbon and nitrogen respectively, forming marsh gas and ammonia, and during the cooling of the products, at a lower temperature, gives rise to the generation of much sulphuretted hydrogen.

In consequence of the great excess of charcoal and sulphur, carbonic oxide, marsh gas and sulphuretted hydrogen are, calculated for 16 mols. of decomposed saltpetre, from four to five times greater in the products of the mining powder than in those of the service powder. The gases of the former are combustible, those of the latter are not.

The potassic sulphocyanate has been formed by the metamorphosis of Curtis and Harvey's powder in quantities ten times as large as were observed amongst the products of the Waltham Abbey mixtures. It is well known that potassic carbonate, sulphur and charcoal, at a white heat, in an atmosphere containing nitrogen, will produce potassic sulphocyanate. The amount of potassic sulphate, as might be expected, present among the products of the mining powder is almost *nil*, and the source of the by-products, of the combustion of gunpowder is laid bare.

If we discard the by-products, we obtain for the combustion of a powder with an excess of carbon the equation:

$$16KNO_3 + 28C + 8S = 4K_2CO_3 + 4K_2S_2 + 12CO_2 + 12CO + 8N_2$$

or more simply:

$$4KNO_3 + 7C + 2S = K_2CO_3 + K_2S_2 + 3CO_2 + 3CO + 2N_2$$

which represents with sufficient exactness the reactions between saltpetre, carbon, and sulphur, when an excess of carbon is present and is introduced in the form of charcoal. Carbonic acid and oxide have been found by experiment to be a little higher, in consequence of the action of the oxygen of the charcoal, potassic carbonate a little lower, in consequence of the formation of some potassic sulphocyanate, than is required by the foregoing equation.

It is also worthy of notice that in spite of the presence of free carbon, more than 13 mols. of CO_2 have remained undecomposed.

From the remarks of the preceding pages it follows that during the complete metamorphosis of powder, the reactions between the constituents of saltpetre, the carbon of the charcoal, and sulphur, take place according to equations (III), (IV), (V), (VI), and (VII), and that by means of equation (VIII) the products, namely, potassic carbonate, potassic sulphate, potassic disulphide, carbonic acid and nitrogen, which are formed during the combustion of a weight of powder containing x mols of saltpetre, y atoms of carbon, and z atoms of sulphur, can be calculated in a satisfactory manner. It now remains to calculate, by means of the same equation, the quantities of heat, gas, and energy which powders of various composition are able to produce.

For this purpose we assume that we have to deal with mixtures of saltpetre, sulphur, and pure *carbon*, and that the combustion is complete, viz. that it runs to the end of the second stage. If we conceive that during the transformation of the powder no carbonic oxide is formed, we should, as a consequence, have a considerable simplification of equation (VIII) without influencing much the calculated amounts of gas and heat.

The conversion of the carbonic oxide to carbonic acid could only take place at the expense of the oxygen in the potassic sulphate; if it occurred according to the equation

$$K_2SO_4 + 4CO = K_2S + 4CO_2$$

the volume of the gas would not be changed. But since potassic disulphide is formed, we have to base our calculations on equation

$$2K_2SO_4 + 7CO = K_2CO_3 + K_2S_2 + 6CO_2$$

from which it follows that, if no carbonic oxide but only carbonic acid is produced, the volume of the entire gas will be diminished by $\frac{1}{7}$th of the volume of the carbonic oxide which in reality is formed.

The greatest amount of carbon in gunpowders generally, as far as I know, is contained in the mixtures of Waltham Abbey, and these also produce the largest quantity of carbonic oxide, 3 mols. or 6 vols. for every 16 mols. of decomposed saltpetre. In addition to 3 mols. of carbonic oxide, 13 mols. of carbonic acid and 8 mols. of nitrogen are generated, which together amount to 24 mols. or 48 vols. of gas.

Now, if in place of carbonic oxide, carbonic acid had been formed, the volume of the entire gas would have been 47.14 instead of 48 vols. In other words, if we frame our calculation on the assumption that only carbonic acid and no oxide has resulted from the combustion, we shall find for the English service powders 1.8 per cent. less gas than was actually obtained by experiment. And as other descriptions of powder contain less carbon than those of Waltham Abbey, in their case the error will be smaller than 1.8 per cent. If then we calculate the volumes of gas which mixtures of saltpetre, carbon, and sulphur in various proportions will produce, on the assumption that no carbonic oxide, but only carbonic acid is formed, we shall obtain numbers that will not differ much from the sum of the volumes of carbonic acid, carbonic oxide, and nitrogen produced by gunpowders containing corresponding quantities of saltpetre, carbon, and sulphur.

By adding the coefficients of carbonic acid and nitrogen of equation (VIII), and putting $x = 16$, and $a = 0$, we obtain for the sum, G, of the molecules of carbonic acid and nitrogen, which a mixture of 16 mols. of saltpetre, y atoms of carbon, and z atoms of sulphur, by its complete combustion, can produce, the equation

$$G = \frac{160 + 20y + 16z}{28}$$

and for the volume, V

$$V = \frac{160 + 20y + 16z}{14} \quad \dots\dots\dots \quad \text{(IX)}$$

In Bunsen and Schischkoff's experiment 16 mols. of saltpetre, 13.3 atoms of carbon, and 6.3 atoms of sulphur were consumed in the

formation of the chief products of combustion (page 42). The values $y = 13.3$, $z = 6.3$, placed in equation (IX), give $V = 37.62$. Now 16 mols. of saltpetre, 13.13 atoms of carbon, and 6.3 atoms of sulphur correspond to 1977.2 parts by weight, and if these parts are expressed in grams, then 1 vol. of gas will be equal to 11.19 litres, and 37.62 vols. = 420967.8 cub. centims. Hence, 1 gram of the powder would produce 212.9 cub. centims. of gas.

But only 92.8 per cent. of the powder was transformed, according to equation (VIII), therefore

$$\frac{212.9 \times 92.8}{100} = 197.5 \text{ cub. centims.}$$

Bunsen and Schischkoff found 193.1 cub. centims. If we deduct from this number 4.5 cub. centims. the volume of the gaseous by-products, hydrogen, sulphuretted hydrogen, and oxygen, and add 7.4 cub. centims. for the carbonic acid of the ammonic carbonate, we obtain 196 cub. centims. for the gas found by experiment.

Hence:

Experiment.	Theory.
196 cub. centims.	197.5 cub. centims.

The chief products of the combustion of Linck's powder contain according to his analysis, the powder constituents in the proportion

$$16KNO_3 + 15.06C + 7.44S.$$

If we substitute in equation (IX) for y the number 15, and for z 7.5, we obtain $V = 41.42$. $16KNO_3 + 15C + 7.5S$ corresponds to 2036 parts by weight. Expressed in grams 1 vol. of the gas will be equal to 11190 cub. centims., therefore 41.42 vols. = 463489.8 cub. centims., and 1 gram of the powder would yield 227.6 cub. centims.

As only 91.7 per cent. of the Würtemberg service powder was transformed, according to equation (VIII), we have

$$\frac{227.6 \times 91.7}{100} = 208.7 \text{ cub. centims. for the theoretical volume.}$$

Linck found 218.35 cub. centims.; but from this must be subtracted 15.67 cub. centims. for sulphuretted hydrogen, 3.56 cub. centims. for hydrogen, and 0.09 for oxygen, leaving 199.3 cub. centims. of gas as the product of combustion of 1 gram of powder

according to equation (VIII). Adding 5.8 cub. centims. for carbonic acid in ammonic carbonate, we obtain

Experiment.	Theory.
205.1 cub. centims.	208.7 cub. centims.

If the difficulties which have to be overcome in order to obtain exact results in the determination of the products of explosion of gunpowder are considered, the differences between the theoretical and experimental numbers appear to come within the errors of observation.

In Noble and Abel's experiments 16 mols. of saltpetre, 21.35 atoms of carbon, and 5.1 atoms of sulphur were transformed according to equation (VIII). If in equation (IX) for y the number 21.35, and for z the number 5.1 is substituted, the volume of gas is found to be 47.73.

$16KNO_3 + 21.35C + 5.1S$ are equal to 2035.4 parts by weight, and 47.73 vols. = 534098.7 cub. centims., if the weight is expressed in grams, therefore 1 gram of the powder yields 262.4 cub. centims. of gas.

On an average, 93.75 per cent. of the weight of the powder was transformed, according to equation (VIII), hence we have:

$$\frac{262.4 \times 93.75}{100} = 246.0 \text{ cub. centims.}$$

for the theoretical volume of gas formed by the combustion of 1 gram of powder. The mean of Noble and Abel's observations is 268.7 cub. centims. From this number 14.5 cub. centims. must be subtracted for the volumes of sulphuretted hydrogen, marsh gas, and hydrogen, leaving 254.2 cub. centims. for the carbonic acid, carbonic oxide, and nitrogen. Therefore we obtain, for the volume of the gas produced by 1 gram of service powder from Waltham Abbey,

Experiment.	Theory.
254.2 cub. centims.	246 cub. centims.

the difference between the two numbers is only 1.9 cub. centim. greater than the greatest difference between two observations made with R. L. G. powder.

The three descriptions of powder, Bunsen and Schischkoff's, Linck's, and Noble and Abel's, contain from 13 to 21 atoms of carbon, and

from 6.3 to 8.4 atoms of sulphur for every 16 mols. of saltpetre, and are good representatives of gunpowder in general.

The values calculated for the volumes of the gases furnished by these powders are near enough to those found by experiment to show the correctness of the theoretical considerations on which equation (IX) has been framed, and to justify the use of this equation for the determination of the volume of gas produced by mixtures which contain saltpetre, carbon, and sulphur in proportions different from those of the Waltham Abbey, the Würtemburg, or Bunsen and Schischkoff's powder.

The amount of heat generated by the combustion of a mixture of saltpetre, *pure* carbon, and sulphur can be found in the following manner:

If we assume, as in the case of the calculation of the gas, that no carbonic oxide is formed, that is to say put $a=0$, multiply the heat of formation of each product with its coefficient in equation (VIII), add the products thus formed and subtract from the sum the heat of formation of saltpetre: the difference will be equal to the heat generated by the combustion of the mixture.

Heat of formation of 1 mol.			$K_2CO_3=279530$*
"	"	"	$K_2SO_4=344640$†
"	"	"	$K_2S_2=108000$‡
"	"	"	$CO_2=97000$§
"	"	"	$KNO_3=119480$‖

Hence we obtain for the heat of combustion, W

$$\left[\tfrac{4}{28}x+\tfrac{8}{28}y-\tfrac{16}{28}z\right]279530+\left[\tfrac{20}{28}x-\tfrac{16}{28}y+\tfrac{4}{28}z\right]344640$$
$$+\left[-\tfrac{10}{28}x+\tfrac{8}{28}y+\tfrac{12}{28}z\right]108000+\left[-\tfrac{4}{28}x+\tfrac{20}{28}y+\tfrac{16}{28}z\right]97000$$
$$-x\times 119480 = W;\ \text{or if } x=16,$$
$$W=1000[1827.154-16.925y-8.788z] \quad \ldots\ldots \quad \text{(X)}$$

* J. Thomsen, Berichte der deutschen chemischen Gesellschaft in Berlin, Bd. xii, p. 2031.

† *Ibid.*, p. 2032; Bd. xiii, p. 961.

‡ Sabatier, Comptes Rendus, tom. xc., 1557–1560; Chem. Soc. Journal, 1880, p. 689.

§ J. Thomsen, Berichte der deutschen chemischen Gesellschaft in Berlin, Bd. xiii, p. 1329.

‖ *Ibid.*, p. 500.

That is to say, a mixture of 16 mols. of saltpetre, y atoms of carbon, and z atoms of sulphur, will, by its complete transformation according to equation (VIII), produce W units of heat.

An error attaches to W in consequence of the assumed non-formation of carbonic oxide.

The quantity of this substance produced by the Waltham Abbey powders is greater than that formed by other mixtures, but as the error attaching to W in the case of the English service powders does not amount to more than 2.6 per cent. of the total heat, an error smaller than the usual errors of observation, it may be neglected for the sake of the great simplification of the formula.

It is perhaps desirable again to call attention to the condition that the equations (IX) and (X) apply only to mixtures which contain their constituents in such proportions that they can completely transform themselves according to equation (VIII). Mining powders are excluded.

The charcoal of gunpowder is, however, not pure carbon, but contains also hydrogen, oxygen and water.

The high temperature generated by the explosion causes probably the dissociation of these elements, and if, as in Noble and Abel's experiments, all the carbon is oxidized at the expense of the oxygen of the saltpetre, the oxygen of the charcoal will reunite with hydrogen and form water.

The heat absorbed by the decomposition of the charcoal is not known. A portion of the hydrogen unites with nitrogen, carbon, and sulphur respectively, forming ammonia, marsh gas, and sulphuretted hydrogen. The total heat which is either liberated or absorbed by all these secondary reactions, appears, however, to be a small quantity, when compared with the amount given off by the formation of potassic carbonate, potassic sulphate, potassic disulphide, and carbonic acid. The following condition has a greater influence on the heat of combustion of ordinary gunpowder.

The combustion ought to be complete; but in Bunsen and Schischkoff's as well as in Linck's experiments, a not inconsiderable portion of the powder remained unburnt. In every calorimetric determination all the products ought to be carefully examined, and this it seems was not done by those who have determined the heat of combustion of gunpowder. From the foregoing remarks we conclude that no close agreement can be expected between the heat of combustion calculated by means of equation (X) for a mixture of 16 mols. of

KNO_3, y atoms of C, and z atoms of S, and that generated by an ordinary gunpowder containing saltpetre, carbon, and sulphur in the same proportions.

In Bunsen and Schischkoff's powder we have for every 16 mols. of saltpetre, 13.3 atoms of C, and 6.3 atoms of S. If we substitute for y the number 13.3 and for z the number 6.3 in equation (X), we obtain:

$$W = 1546688 \text{ cal.}$$

$16KNO_3 + 13.3C + 6.3S = 1977.2$ parts by weight, or one part of their powder would furnish 782 units of heat. Bunsen and Schischkoff found 619.5. This number is, I believe, the result of one experiment made with 0.71 gram of powder; it is evidently much too small. Noble and Abel found, for the heat of combustion of the powders of Waltham Abbey, values which vary between 696 and 727 units. Their numerous calorimetric determinations were made by the combustion of the powders in the explosion apparatus, and several hundred grams were used in each experiment. It is known that the combustion under such conditions is complete. But as the English powders contain much more carbon than Bunsen and Schischkoff's, or 4 per cent. less of saltpetre, they ought to have produced less heat. From these considerations it seems to follow that in Bunsen and Schischkoff's experiment a portion of the powder taken escaped combustion.

It has been shown that 16 mols. of saltpetre, 21 atoms of C, and 5 atoms of S take part in the metamorphosis of the powders of Waltham Abbey. If for y the number 21, for z the number 5, are substituted in equation (X), the value of W is found to be equal to 1427789 cal.; but $16KNO_3 + 21C + 5S = 2028$ parts by weight, hence 1 gram of powder would generate 704 units of heat.

Noble and Abel found in the first series, comprising five experiments, numbers which give a mean of 702.34 units for 1 gram of powder.

In another series of 19 experiments greater numbers were obtained than in the first. The mean of all 24 experiments is equal to 719.9 cal.

The theoretical number of 704 cal., however, corresponds to a mixture of saltpetre, sulphur, and pure carbon.

93.75 per cent. of the English service powders are transformed, according to equation (VIII), hence the calculated heat generated by

the reactions between saltpetre, sulphur, and pure carbon of 1 gram of English service powder is:

$$\frac{704 \times 93.75}{100} = 660 \text{ cal.}$$

This theoretical quantity is 59.9 units, or 8.4 per cent. less than the amount found by experiment, a difference which would be much smaller if the amount of heat produced by the action of the sulphur upon the iron of the apparatus were known and could be subtracted from the experimental number. It is worthy of notice that the differences in the amounts of heat found in several experiments made with the same description of powder are nearly as great as the differences between the calculated and observed results.

A sample of powder manufactured by Curtis and Harvey, and marked No. 6, gave in four experiments

I.	II.	III.	IV.
732.9	744.9	755.7	784

units of heat, hence, between the first and last experiment a difference of 51.1 units.

Another heat determination may be here introduced. $16KNO_3 + 16.4C + 5.5S$ of the Spanish pebble powder burnt according to the reactions on which equation (VIII) is based, 16.4 for y, and 5.5 for z put in equation (X), make $W = 1501250$ cal.

As

$$16KNO_3 + 16.4C + 5.5S$$

are equal to 1988.8 parts by weight, 1 gram of the powder generates 754 cal.

If 5 per cent. are deducted for hydrogen, oxygen, and ash, we obtain:

$$\frac{754 \times 95}{100} = 716.3 \text{ cal.}$$

for the calculated heat of 1 gram of powder. Experiment gave 762.3, or 46 units more.

It follows as a general result from these considerations that the mean quantities of heat generated by the combustion of the English service and Spanish pebble powders are about 60 units greater than the theoretical values. If, however, the amount of heat generated by the action of the sulphur upon the iron of the explosion apparatus

were known, and could be subtracted from the observed quantities of heat, the difference would become much smaller.

On the other hand, the theoretical numbers stand to each other nearly in the same ratios as do the corresponding experimental values.

The equations (VIII), (IX), and (X) will now be used to determine the composition of an ideal powder, that is to say, of a powder composed of saltpetre, *pure* carbon, and sulphur, which shall, of all possible mixtures of this nature, possess the greatest energy; the results so obtained will be nearly correct for ordinary gunpowders. This would be the most general form of the problem of the explosion of gunpowder which could be proposed for solution to a chemist.

Equations (IX) and (X), viz:

$$V = +\tfrac{160}{14} + \tfrac{20}{14}y + \tfrac{16}{14}z \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(IX)}$$
$$W = 1000[1827.154 - 16.925y - 8.788z] \quad . \quad . \quad . \quad \text{(X)}$$

at once show that, if for a given weight of saltpetre, 16 mols., the carbon and sulphur of the mixture were allowed to increase, the volume of gas generated by combustion would likewise increase, but the quantity of heat will grow smaller, and if the carbon and sulphur be diminished the gas will also become less, but the heat of combustion will increase.

Noble and Abel have called attention to the fact* that the products of heat and gas obtained by them in their various experiments with different descriptions of powder do not differ much from each other. The explanation of this interesting observation is to be found in equations (IX) and (X).

The work which can be performed by a given weight of powder will *cæteris paribus*, be proportional to the volume of gas and amount of heat, respectively, which the powder can produce by its combustion, and, hence, will be proportional to the product of both. This is, however, only approximately correct, because, if we have to compare the work which two powders of different composition can produce, the gases given off by the one will not contain the elements in the same proportion as those produced by the other; a portion of the energy developed will be consumed in the performance of interior work during the expansion of the carbonic acid. This portion is, however, very small.

* Phil. Trans., 1880, p. 230.

The product of (IX) and (X) is:

$$10440.88 - 12.09y^2 + 1208.39y - 15.95yz + 993.867z - 5.022z^2 =$$

$$\frac{W.V}{1000 \times 2} = E \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad \text{(XI)}$$

the factor 1000 in (X) has been omitted, or W divided by 1000, and V by division by 2 has been converted from volumes into molecules.

The equations (IX) and (X) are based on the assumption that no carbonic oxide is formed during the combustion of a mixture of saltpetre, carbon, and sulphur. In consequence, the volume of gas calculated by formula (IX) for a mixture of the composition like those of Waltham Abbey is 1.8 per cent. smaller, and the amount of heat according to equation (X) 2.6 per cent. larger than it would have been if the carbonic oxide had been taken into consideration. These errors nearly compensate each other in the product E in the equation (XI), so that the values of E are but *little* affected by putting a, the carbonic oxide, $=0$ in equation (VIII).

Equation (XI) can be used for the calculation of the relative energies of weights of powder containing 16 mols. of saltpetre, y atoms of carbon, and z atoms of sulphur.

The question now arises for what values of y and z will E in equation (XI) assume a maximum value, provided that y and z render the coefficients of equation (VIII) positive,—the condition which must be fulfilled in a chemical equation.

If we put $a=0$ in equation (VIII), we obtain:

$$\left.\begin{matrix} xKNO_3 \\ +yC \\ +zS \end{matrix}\right\} = \left\{\begin{matrix} \frac{1}{28}[4x + 8y - 16z](K_2CO_3) \\ +\frac{1}{28}[20x - 16y + 4z](K_2SO_4) \\ +\frac{1}{28}[-10x + 8y + 12z](K_2S_2) \\ +\frac{1}{28}[-4x + 20y + 16z](CO_2) \\ +\frac{1}{2}xN_2 \end{matrix}\right. \quad . \quad . \quad . \qquad \text{(XII)}$$

in which, as in (VIII), x, y, and z denote positive numbers. Let a rectangular coordinate system be given with its origin in point A, and the coordinates of a point P be represented by x, y, and z. The coefficients of potassic carbonate, sulphate, and disulphide in (XII) will for certain values of x, y, and z be equal to 0. The equations:

$$\begin{aligned} 4x + 8y - 16z &= 0 \\ 20x - 16y + 4z &= 0 \\ -10x + 8y + 12z &= 0 \end{aligned}$$

satisfied by these values represent three planes which form a trihedral angle with its vertex in the origin and one edge in the x A y plane. The points within the trihedral angle have coordinates which will render all the coefficients of (XII) positive, those situated outside give values for x, y, and z, which will make at least one of the three coefficients of the potassium salts negative. Hence, coordinates of the points within the trihedral angle denote quantities of saltpetre, carbon, and sulphur which can transform themselves completely into potassic carbonate, sulphate, disulphide, carbonic acid, and nitrogen, whereas the points outside represent, by their coordinates, quantities of the powder constituents which cannot do so entirely, because one or the other of these constituents is in excess or defect.

The points on the faces of the trihedral angle correspond to mixtures which will burn with the production of two, those on the edges with only one, of the three potassium salts.

But to show the connection between the quantities of the constituents of a given powder and those of its products of combustion, we need only consider relative, and not absolute quantities.

If a straight line be drawn through the origin within the trihedral angle, the ratios of the coordinates of every point upon it will be the same.

A plane at right angles to the x axis will cut the faces of the trihedral angle so as to form a triangle B D C (see Fig. 1), and the coordinates of the points inside this triangle will represent all possible proportions of carbon and sulphur which can with a given weight of saltpetre transform themselves into the products of combustion indicated in equation (XII). If then in (XII) we attribute to x the constant value 16, we obtain:

$$\left.\begin{array}{l} 16KNO_3 \\ +yC \\ +zS \end{array}\right\} = \left\{\begin{array}{l} \frac{1}{28}[\ \ 64 + 8y - 16z](K_2CO_3) \\ +\frac{1}{28}[\ \ 320 - 16y + 4z](K_2SO_4) \\ +\frac{1}{28}[-160 + 8y + 12z](K_2S_2) \\ +\frac{1}{28}[-\ 64 + 20y + 16z](CO_2) \\ +8N_2 \end{array}\right. \quad . \ . \quad \text{(XIII)}$$

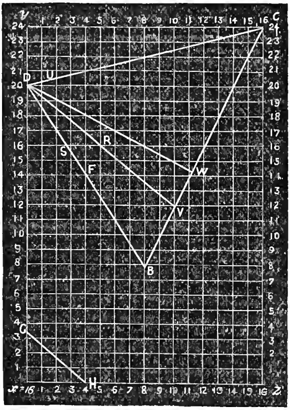
and from it the equations:

$$64 + 8y - 16z = 0 \quad . \ . \ . \ . \ . \ . \quad \text{(XIV)}$$
$$320 - 16y + 4z = 0 \quad . \ . \ . \ . \ . \ . \quad \text{(XV)}$$
$$-160 + 8y + 12z = 0 \quad . \ . \ . \ . \ . \ . \quad \text{(XVI)}$$

of the lines of intersection of the plane at right angles to the x axis

with the faces of the trihedral angle, in other words, the sides of the triangle B D C (Fig. 1).

Fig. 1.



It will be observed that

(XIV)	is the equation of		B C
(XV)	"	"	D C
(XVI)	"	"	B D.

The points of the side B C represent, by their coordinates, mixtures of carbon and sulphur with 16 mols. of saltpetre, which will by complete combustion produce no potassic carbonate; those of side D C such as will not form potassic sulphate, and finally, the coordinates of the points of side B D denote quantities of carbon and sulphur which will burn with 16 mols. of saltpetre without the formation of potassic disulphide. The coefficient of carbonic acid will never vanish, but be always positive, because if it is equated to zero it will represent the line G H in figure, which does not intersect the triangle B D C.

All points outside the triangle B D C have coordinates which render at least one of the three coefficients of the potassium salts in equation (XIII) negative, and consequently have reference to mixtures of carbon and sulphur with 16 mols. of saltpetre, which contain either too much or too little of one or both of the two elements named.

The coordinates of the line B D represent mixtures of carbon and sulphur with 16 mols. of saltpetre, which will burn without the formation of potassic disulphide, and those of the line B C, such as will not produce potassic carbonate; hence, it may be concluded that the coordinates of B, the point of intersection of the two lines, will correspond to a powder which will be transformed without formation of potassic carbonate and disulphide, and will only yield, as products of its combustion, potassic sulphate, carbonic acid, and nitrogen. The coordinates of point B are:

$$y = 8$$
$$z = 8$$

and these values substituted in equation (XIII),

$$16KNO_3 + 8C + 8S = 8K_2SO_4 + 8CO_2 + 8N_2$$

or simplified:

$$2KNO_3 + C + S = K_2SO_4 + CO_2 + N_2$$

Accordingly a mixture of 82.1 parts of saltpetre, 4.8 parts pure carbon, and 13 parts of sulphur may be expected to produce during complete combustion only potassic sulphate, carbonic acid, and nitrogen, and this conclusion is in perfect accord with the thermochemical relations of the reacting substances and with experimental results. And by a similar method of reasoning we arrive at the conclusion that the coordinates of the point D represent a mixture which will burn according to the equation:

$$16KNO_3 + 20C = 8K_2CO_3 + 12CO_2 + 8N_2$$

or simplified:

$$4KNO_3 + 5C = 2K_2CO_3 + 3CO_2 + 2N_2$$

and those of point C according to

$$16KNO_3 + 24C + 16S = 8K_2S_2 + 24CO_2 + 8N_2$$

or simplified:

$$2KNO_3 + 3C + 2S = K_2S_2 + 3CO_2 + N_2$$

if in this last equation the potassic disulphide be changed into monosulphide, then the equation would become identical with the old one, which for many years was supposed to represent the metamorphosis of all sorts of gunpowders.

As already observed, all points within the triangle represent, by their coordinates, mixtures of carbon and sulphur with 16 mols. of

KNO_3, which besides carbonic acid and nitrogen, will yield during their combustion three potassium salts.

The geometrical construction of the coefficients of equation (XIII) does not only offer the advantage of representing by the coordinates of the points within the triangle B D C all possible proportions of saltpetre, carbon, and sulphur which can transform themselves into potassic carbonate, potassic sulphate, potassic disulphide, carbonic acid and nitrogen, but it also enables us to deduce at once, geometrically, the quantities of these products of combustion.

If we desire to know the composition of all these mixtures which contain variable quantities of carbon and sulphur, but shall all produce by their combustion the same amount of potassic carbonate, we can deduce the answer from the following considerations:

For such mixtures the coefficient of the potassic carbonate in equation (XIII) must assume a constant value. Hence,

$$64 + 8y - 16z = c$$

and

$$y = 2z + \frac{c - 64}{8}$$

the equation of a line parallel to the side B C of the triangle. The coordinates of the points of such a line indicate the composition of mixtures which will burn with production of the same amount of potassic carbonate. The amount of potassic carbonate is constant for each parallel line, but changes from one line to another. Now as they intersect the lines B D and D C, it is only necessary to ascertain the amounts of potassic carbonate corresponding to the points of one of these sides in order to know the amount of potassic carbonate formed by the combustion of a mixture represented by the coordinates of any point within the triangle.

Similar considerations lead to the equation:

$$y = \tfrac{1}{4}z + \frac{320 - c}{16}$$

for mixtures which will burn with production of equal quantities of potassic sulphate.

This is the equation of a line parallel to the side D C. All these parallel lines intersect the line D B. If, then, we know the quantity of potassic sulphate corresponding to each point of D B, we shall likewise know the amount of this salt which any mixture, the composition of which is represented by the coordinates of one of the points

of the triangle, can produce by its combustion. Now the powders, the composition of which is given by the coordinates of the points of B D, produce by their combustion an amount of potassic sulphate which in molecules is directly expressed by the length of the corresponding abscissæ of the points.

Since x has been taken constant $=16$, the sum of the molecules of the potassium salts must always be $=8$, and as the points of the line B D represent only mixtures which burn with the production of two of these salts, potassic carbonate and sulphate, it is only necessary in order to know the respective quantities of each of these salts for a point F on B D, to subtract the value of the abscissa of F from 8 to obtain the molecules of potassic carbonate which would be produced by the combustion of a mixture the composition of which is given by the coordinates of F.

The coefficient of potassic disulphide in equation (XIII) is $=-160+8y+12z$, from which we deduce the equation:

$$y=-\tfrac{3}{2}z+\frac{c+160}{8}$$

which is the equation of a line parallel to side B D. The points of such a line represent by their coordinates mixtures which will burn with the production of the same amount of potassic disulphide, which amount is constant for the same line, but changes from one to another. This amount is found for a mixture represented by the coordinates of a point P, if through P a line is drawn parallel to B D, and the abscissa of the point of intersection with the side D C is ascertained; half the length of this abscissa represents the number of molecules of potassic disulphide formed by the combustion of the mixture represented by point P.

For mixtures which are to burn with the evolution of the same quantity of carbonic acid we have:

$$-64+20y+16z=c$$

or

$$y=-\tfrac{4}{5}z+\frac{c+64}{20}$$

an equation which represents a line parallel to G H, on which for two points y, z and y', z', five times the difference of the ordinates is equal to four times the difference of the abscissæ.

The line D V in our figure is parallel to G H. In order to find the amount of carbonic acid which is developed by the combustion of a mixture the composition of which is represented by the coordinates

of a point P, we have to draw through P a line parallel to D V or G H, and determine the length of the ordinate of the point of intersection with the side B C; this length is equal to the number of molecules of carbonic acid, because for all mixtures represented by the points of the side B C, the number of molecules of carbonic acid produced is equal to the number of atoms of carbon the mixtures contain.

We will now proceed to determine, by aid of the method just explained, the quantities of the products of combustion of a mixture the composition of which is represented by the coordinates of the point R on D V, $y = 16$, $z = 5$. A line drawn through R parallel to D C intersects D B in the point S; the abscissa of $S = 3$, hence 3 mols. of potassic sulphate are produced.

A line drawn through R parallel to B C, cuts the side D B, in F; the abscissa of $F = 4$; $8 - 4 = 4$; hence we obtain 4 mols. of potassic carbonate.

A line through R parallel to D B, intersects D C, in point U; the abscissa of $U = 2$; $\frac{2}{2} = 1$; hence 1 mol. of potassic disulphide is formed.

R is a point of D V, the ordinate of V, y, $= 12$, hence we have 12 mols. of carbonic acid.

Nitrogen is for all mixtures a constant $= 8N_2$, therefore the equation for the metamorphosis of a mixture, the composition of which is expressed by the coordinates of the point R, is:

$$16KNO_3 + 16C + 5S = 4K_2CO_3 + 3K_2SO_4 + K_2S_2 + 12CO_2 = 8N_2$$

The great advantage of the geometrical construction of the coefficients of equation (XIII) consists in this, that we can at once ascertain by an inspection of figure B C D, the influence of all possible variations of the quantities of carbon and sulphur in given mixtures, upon the proportions of the corresponding products of combustion.

Similar considerations enable us to find the quantities of gas and heat.

If we add the constant 8 for nitrogen to the number of molecules of carbonic acid determined as previously explained, we obtain the total number of gas molecules produced by the combustion of a mixture represented by the coordinates of a given point.

The heat generated is found by equation (X).

For powders which shall produce by their combustion the same amount of heat, we have:

$$1.92y = -z + \frac{1827154 - c}{8788}$$

for which we may adopt without serious error

$$2y = -z + \frac{1827154 - c}{8788} \quad . \quad . \quad . \quad . \quad (XVII)$$

This is the equation of a line perpendicular to the side B C. For an appropriate value of C it becomes:

$$2y = -z + 40$$

and then represents the line D W in the figure.

Mixtures, the composition of which can be represented by the points of such a line, will generate by their combustion very nearly the same amount of heat. A powder composed of $16KNO_3 + 20C$ corresponds to the point D, and one consisting of $16KNO_3 + 14.4C + 11.25S$ to the point W. The first generates according to equation (X) 1,488,654, and the second 1,484,569 units of heat, two numbers which differ only by 0.27 per cent., and may therefore be considered identical for practical purposes.

A line drawn through the point R, perpendicular to the side B C, intersects the latter in the point $y = 13.25$, $z = 10.6$; hence two powders composed of

$$16KNO_3 + 16C + 5S$$
$$\text{and } 16KNO_3 + 13.25C + 10.6S$$

will generate by their combustion the same, or more correctly, nearly the same amount of heat.

Consequently, if we know the heat of combustion of all the mixtures represented by the coordinates of the points of the line B C, then we know likewise the heat of combustion of all the mixtures the composition of which is represented by *any* point within the triangle. And we arrive at the same conclusion with regard to the amount of gas which a mixture can produce, the composition of which is represented by any point inside the triangle B C D. According to equation (X) the heat of combustion reaches its maximum when y and z assume their smallest values, and, on the other hand, when y and z are greatest the heat of combustion will be a minimum. Therefore, an inspection of the triangle B D C teaches that of all the infinite number of mix-

tures of saltpetre, carbon, and sulphur which can be transformed according to equation (XIII), the one which is composed of

$$16KNO_3 + 8C + 8S$$

will produce by its combustion the greatest, and the one composed of

$$16KNO_3 + 24C + 16S$$

the smallest quantity of heat: the first is represented by point B, the second by point C of the figure.

Further, it follows from equation (IX) that the first of the above mixtures will form the smallest, and the second the largest quantity of gas.

If then we place ourselves at the point B of line B C, to which corresponds the generation of the greatest quantity of heat and that of the smallest quantity of gas, and move from B towards C, the amounts of heat produced by the mixtures represented by the coordinates of the several points will constantly decrease, and the volumes of gas increase, until the former reach in C their minimum, and the latter their maximum value.

We calculate for B and C

	Volume of gas.	Units of heat.
B	32	1,621,450
C	64	1,280,346

and between these numbers, 32 and 64 for the volume of the gas, and 1,280,346 and 1,621,450 for the units of heat, fluctuate the quantities of heat and gas which any possible mixture of 16 mols. of saltpetre with carbon and sulphur can produce, provided that these constituents, during combustion, transform themselves according to equation (XIII). We will now show that the product, E, of the units of heat and the molecules of gas as given by equation (XI), is greater for mixtures represented by points of line B C than for such as are represented by any other point within the triangle.

If we take, on the line D W, perpendicular to B C, the point $y = 17$, $z = 6$, then the mixture corresponding to this point and the one corresponding to point W will produce the same quantity of heat. The amount of gas generated by the mixture represented by point $y = 17$, $z = 6$, must be less than the quantity produced by the mixture corresponding to point W. Because, if we draw a line through $y = 17$, $z = 6$, parallel to D V, the point of intersection with B C will lie between W and V, but the further the point of intersec-

tion is away from W in the direction towards B the smaller the volumes of gas will be. Hence, the product of gas and heat for $y = 17$, $z = 6$ must be smaller than the one for point W, and the further we proceed from W towards D the smaller this product must be. But what holds good for the line D W also applies to every other perpendicular which can be drawn to B C.

Therefore the maximum value of the product of gas and heat must be produced by a mixture the composition of which is expressed by the coordinates of one of the points of the line B C.

If we represent the function on the right of the equation (XI) by $F(y, z)$, and the equation of the line B C (XIV) by $\varphi(y, z) = 0$, then the differential equation

$$\frac{dF}{dz} \cdot \frac{d\varphi}{dy} - \frac{dF}{dy} \cdot \frac{d\varphi}{dz} = 0$$

together with $\varphi(y, z) = 0$ give the values of y and z, for which E in equation (XI) becomes a maximum. We find $y = 38.02$ and $z = 23.0$. Hence, a powder composed of

$$16KNO_3 + 38C + 23S$$

will by its complete combustion produce amounts of heat and gas the product of which will be the required maximum. But a mixture which shall transform itself according to equation (XIII) can only contain per 16 mols. of saltpetre from 8 to 24 atoms of carbon, and from 8 to 16 atoms of sulphur. Hence, the product of the quantities of heat and gas will be a maximum for a powder composed of

$$16KNO_3 + 24C + 16S$$

because according to the coefficients of equation (XI) E will become greater and greater when y increases from 8 to 24, and z from 8 to 16, until it reaches its maximum value at a point $y = 38$ and $z = 23$, outside the triangle B C D.

For the purpose of calculating the values of E for different mixtures, we may simplify the coefficients and constant of equation (XI), and write accordingly

$$10441 - 12.1y^2 + 1208.4y - 16yz + 994z - 5z^2 = E \quad . \quad . \quad \text{(XVIII)}$$

E has been calculated by means of this equation for different values of y and z with the following results:

$y = 8$,	$z = 8$,	$E = 25941.8$
$y = 10$,	$z = 9$,	$E = 28416$
$y = 12$,	$z = 10$,	$E = 30719.4$
$y = 14$,	$z = 11$,	$E = 32852$
$y = 16$,	$z = 12$,	$E = 34813.8$
$y = 18$,	$z = 13$,	$E = 36604.8$
$y = 20$,	$z = 14$,	$E = 38225$
$y = 22$,	$z = 15$,	$E = 39674.4$
$y = 24$,	$z = 16$,	$E = 40953.0$

If, therefore, the carbon and the sulphur increase in different mixtures, the carbon by 2 atoms and the sulphur by 1 atom from

$$16KNO_3 + 8C + 8S$$

to

$$16KNO_3 + 24C + 16S$$

then parallel with this change of the carbon and sulphur, a regular increase of the product of heat and gas takes place, until for 24C and 16S it becomes a little more than one and-a-half times as great as for 8C and 8S.

If saltpetre and sulphur remain constant, and the carbon alone changes, then also an increase of the carbon is followed by one of E.

$y = 8$,	$z = 8$,	$E = 25941.8$
$y = 16$,	$z = 8$,	$E = 32261.8$
$y = 18$,	$z = 8$,	$E = 33599.8$
$y = 22$,	$z = 8$,	$E = 35985.8$

The energy of a powder of the composition:

$$16KNO_3 + 22C + 8S$$

is about $\frac{2}{5}$ths greater than that of one containing

$$16KNO_3 + 8C + 8S.$$

If saltpetre and carbon are constant, but the sulphur changes, we obtain the following values for E:

$y = 14$,	$z = 4$,	$E = 27987.0$
$y = 14$,	$z = 11$,	$E = 32852.0$
$y = 16$,	$z = 6$,	$E = 30925.8$
$y = 16$,	$z = 8$,	$E = 32261.8$
$y = 16$,	$z = 12$,	$E = 34813.8$

$y = 18$,	$z = 8$,	$E = 33599.8$
$y = 18$,	$z = 13$,	$E = 36604.8$
$y = 20$,	$z = 0$,	$E = 29769$
$y = 20$,	$z = 5$,	$E = 33014$
$y = 20$,	$z = 9$,	$E = 35430$
$y = 20$,	$z = 14$,	$E = 38225$
$y = 22$,	$z = 8$,	$E = 35985.4$
$y = 22$,	$z = 15$,	$E = 39674.4$

It follows from these examples that for a constant quantity of saltpetre, in varying mixtures of saltpetre, carbon, and sulphur, the relative energy of the mixtures increases with both the carbon and the sulphur, and reaches its maximum for 24 atoms of carbon and 16 atoms of sulphur, the highest amounts of these constituents which can exist in a powder according to equation (XIII).

The difference of E for two mixtures of the same amount of saltpetre, but varying quantities of carbon and sulphur, becomes much smaller with equal weights of such mixtures. If, then, we multiply x, y, and z with their respective molecular or atomic weights, and divide E by the sum of the numbers so obtained, we find the relative energy, say E′, of equal weights of various mixtures.

The following table gives the value of E′ for mixtures which contain 16 mols. of KNO_3, y atoms of C, and z atoms of S.

$y = 8$,	$z = 8$,	$E' = 13.18$
$y = 16$,	$z = 8$,	$E' = 15.63$
$y = 18$,	$z = 8$,	$E' = 16.09$
$y = 22$,	$z = 8$,	$E' = 16.84$
$y = 11$,	$z = 6$,	$E' = 13.91$
$y = 13$,	$z = 6$,	$E' = 14.58$
$y = 16$,	$z = 6$,	$E' = 15.46$
$y = 21$,	$z = 6$,	$E' = 16.62$
$y = 11$,	$z = 6$,	$E' = 13.91$
$y = 11$,	$z = 9.5$,	$E' = 14.41$
$y = 14$,	$z = 4$,	$E' = 14.63$
$y = 14$,	$z = 8$,	$E' = 15.11$
$y = 14$,	$z = 11$,	$E' = 15.38$

$y=16$,	$z=2.66$	$E'=15.11$
$y=16$,	$z=6$,	$E'=15.46$
$y=16$,	$z=8$,	$E'=15.63$
$y=16$,	$z=12$,	$E'=15.88$
$y=18$,	$z=8$,	$E'=16.09$
$y=18$,	$z=13$,	$E'=16.28$
$y=20$,	$z=0$,	$E'=16.03$
$y=20$,	$z=5$,	$E'=16.37$
$y=20$,	$z=9$,	$E'=16.52$
$y=20$,	$z=14$,	$E'=16.59$
$y=21$,	$z=4$,	$E'=16.54$
$y=21$,	$z=6$,	$E'=16.62$
$y=22$,	$z=8$,	$E'=16.84$
$y=22$,	$z=15$,	$E'=16.81$
$y=24$,	$z=16$,	$E'=16.95$

It follows from these numbers that E′ becomes greater when y or z, or both simultaneously, increase, but proportionately less so than is the case with weights of mixtures which contain equal weights of saltpetre, viz. 16 mols.

The smallest value of E′ is 13.18, the highest 16.95; hence the latter is about 28 per cent. greater.

The highest value of E, on the other hand, is more than 50 per cent. greater than the lowest. Further, it is apparent that for mixtures for which y and z assume high values the differences of E′ become very small.

The powder

$$16KNO_3+14C+4S$$

differs from

$$16KNO_3+14C+11S$$

by 7 atoms of sulphur.

The two mixtures

$$16KNO_3+22C+8S$$
$$\text{and } 16KNO_3+22C+15S$$

differ by the same amount of sulphur.

The two former show, for E′, the difference 0.75, the latter only 0.03; indeed, many of the various mixtures for which y and z have high values, give, when equal weights are considered, almost the same number for E′.

If we draw a line through the triangle B C D (see Fig. 1), from the point $y = 22$, $z = 8$ to the point $y = 8$, $z = 8$, it will be observed that for mixtures represented by the coordinates of the points on the right-hand side of this line, the value of E′ only increases very little if the sulphur is increased beyond 8 atoms and the carbon kept constant. This circumstance is of great practical importance. The analyses of military and sporting powders known to me, all give for 16 mols. of saltpetre an amount of sulphur which varies between 5.5 and 8.7 atoms. There would be very little, if any, gain in energy if, for 16 mols. of saltpetre, more than about 8 atoms of sulphur were introduced into the powder; especially would this be the case with mixtures in which for 16 mols. of saltpetre more than 16 atoms of carbon are present.

E′ obtains its maximum value, 16.95, when the powder contains:

$$16KNO_3 + 24C + 16S.$$

Such a large amount of sulphur does not, according to the foregoing remarks, contribute much to the value of E′, whereas, on the other hand, it must be very detrimental to the metal of the ordnance. For the mixture

$$16KNO_3 + 22C + 8S$$

we have E′ = 16.84, hence, only 0.67 per cent. less than for $16KNO_3 + 24C + 16S$.

If carbon and sulphur undergo a further diminution, the decrease of E′ becomes more rapid; for

$$16KNO_3 + 21C + 4S$$

E′ = 16.54. If, therefore, we had to choose between the two mixtures

$$16KNO_3 + 24C + 16S$$
and $$16KNO_3 + 22C + 8S$$

for the composition of a service powder, the second would recommend itself as the more suitable.

We will now compare the composition and energy of the ordinary gunpowders with the results of the foregoing theoretical considerations.

The composition of the powders of Waltham Abbey can be represented by the symbols:

$$16KNO_3 + 21.18C + 6.63S$$

which corresponds nearly to 75 parts of saltpetre, 10 parts of sulphur, and 15 parts of charcoal.

About these numbers fluctuate the compositions of the service powders of most nations.

	Composition of Gunpowders.		
	Saltpetre.	Charcoal.	Sulphur.
England	75	15	10
Sweden	75	15	10
Russia	75	15	10
Prussia	74	16	10
Saxony	74	16	10
United States	76	14	10
Austria	75.5	14.5	10

If, therefore, the composition of a gunpowder is required which shall possess nearly the greatest energy, and at the same time contain the smallest amount of sulphur compatible with this condition, an experience extending over 500 years has selected a mixture which contains saltpetre, carbon, and sulphur nearly in the theoretical proportions.

Composition of powders of Waltham Abbey . . . . $16KNO_3 + 21.18C + 6.63S$
Theoretical composition . . . . . . $16KNO_3 + 22C + 8S$.

We concluded from Karolyi's experiments that the most inflammable and combustible mixture is represented by

$$16KNO_3 + 13C + 5S.$$

Bunsen and Schischkoff found in their sporting powder

$$16KNO_3 + 13.3C + 6.3S.$$

The value of E′ for the proportions of saltpetre, carbon, and sulphur exhibited in the powders of Waltham Abbey is very nearly 16.62; for Bunsen and Schischkoff's sporting powder 14.58. Consequently 1.22 per cent. of the energy of the English service powder has been sacrificed in order to obtain the greater combustibility of the sporting powder.

According to composition, the service powders of France, Spain, Belgium, and Würtemberg are intermediate between the two powders just considered. They fluctuate about the proportions required by the symbols

$$16KNO_3 + 16C + 8S$$

E' for these powders equals 15.63, or about 6 per cent. less than for the English; but they will, probably, be more inflammable and combustible than the latter.

It is worthy of notice that the points which represent, by their coordinates, the proportions of saltpetre, carbon, and sulphur in the gunpowders considered in this paper, are situated between two ordinates on our triangle B C D, for which respectively z assumes the values 5.5 and 8.7. The powders of Waltham Abbey, and Bunsen and Schischkoff's sporting powder contain per 16 mols. of saltpetre, nearly the same amount of sulphur; the former are represented by a point near the line D C, the latter by one near the line B D, of our figure B C D.

Summary of the Main Results.

1. The mean composition of the powders of Waltham Abbey can be represented by the symbols:

$$16KNO_3 + 21.18C + 6.63S$$

A powder of this composition is transformed in Noble and Abel's apparatus according to the equation:

$$16KNO_3 + 21C + 5S = 5K_2CO_3 + K_2SO_4 + 2K_2S_2 + 13CO_2 + 3CO + 8N_2 \qquad \text{(II)}$$

The residue of the sulphur, 1.63 atoms, unites partly with hydrogen, partly with the iron of the apparatus.

2. The ordinary service and sporting powders contain for every 16 mols. of saltpetre from 13 to 22 atoms of carbon, and from 5.5 to 8.7 atoms of sulphur.

3. A powder composed of *pure* carbon, saltpetre, and sulphur furnishes by its *complete* combustion potassic carbonate, potassic sulphate, potassic *disulphide*, carbonic acid, carbonic oxide, and nitrogen, as chief products.

4. An increase of pressure appears, *cæteris paribus*, to diminish the amount of carbonic oxide, and, in consequence, according to equation (VIII), to increase the quantities of potassic carbonate, potassic disulphide, and carbonic acid, and diminish that of potassic sulphate. These fluctuations depending on pressure are, however, *very small*. In Noble and Abel's Experiment No. 38, the pressure amounted to 18.6 tons, in Experiment No. 77 to 31.4 tons on the square inch,

Experiment No. 38 gave for every 16 mols. of decomposed saltpetre 3.36 mols. of carbonic oxide, and Experiment No. 77, 2.9 mols. of this gas, or, for a difference of 12.8 tons in pressure, one of 0.46 mol. of carbonic oxide. A diminution of 0.5 mol. of carbonic oxide corresponds to one of 0.143 mol. in the amount of potassic sulphate, and an increase of 0.071 mol. in that of the potassic carbonate and disulphide, and 0.428 mol. in the quantity of carbonic acid. These fluctuations are probably not caused directly by the pressure, but by the differences in the rate of cooling after explosion.

5. The combustion of gunpowder takes place in two stages, one succeeding the other.

(*a.*) A process of oxidation during which potassic and sulphate, carbonate, carbonic acid and nitrogen, and, *perhaps*, some carbonic oxide, but no potassic disulphide, are produced.

(*b.*) A process of reduction during which carbon and sulphur left free at the end of the first stage react with some of the products formed during that stage; the free carbon reducing potassic sulphate, with formation of potassic disulphide, potassic carbonate, and carbonic acid; the free sulphur decomposing potassic carbonate with the production of potassic disulphide, potassic sulphate, and carbonic acid [equations (V) and VI)].

6. The first stage of the combustion, the explosion proper, takes place with powders of various composition according to equation:

$$10KNO_3 + 8C + 3S = 2K_2CO_3 + 3K_2SO_4 + 6CO_2 + 5N_2 \quad . \quad \text{(III)}$$

But as some carbonic oxide is probably produced at the same time, the following will more correctly represent the reactions:

$$\begin{aligned} 16KNO_3 + 13C + 5S = 3K_2CO_3 + 5K_2SO_4 + 9CO_2 \\ + CO + 8N_2 \quad . \ . \ . \ . \ . \ . \ . \ . \quad \text{(IV)} \end{aligned}$$

The constituents of the powder and the products of combustion are, according to (IV), nearly in the same ratios as according to (III).

7. The oxygen in the potassic carbonate stands to the oxygen in the potassic sulphate and carbonic acid, respectively, in equation (III), in the most simple ratios which can exist, if these substances are to be produced by the combustion of a mixture of saltpetre, carbon, and sulphur. In other words, equation (III) represents the most simple distribution of the oxygen of the decomposed saltpetre amongst the products of the first stage of the combustion. And

because the products are, according to equation (IV), nearly in the same proportions they assume to (III), it follows that the distribution of the oxygen between potassic sulphate, carbonate, and carbonic acid, according to (IV), nearly corresponds to the most simple possible distribution.

8. If the greatest possible amount of heat is to be evolved by the combustion of a mixture of saltpetre, carbon, and sulphur, and if at the same time potassic sulphate, carbonate, and carbonic acid are to be formed in such proportions that the heat of formation of one of them shall stand to the heat of formation of each of the others in the most simple ratio, then the combustion must take place according to equation (IV).

The heat produced by the formation of 3 mols. of potassic carbonate stands to that produced by the formation of 5 mols. of potassic sulphate and 9 mols. of carbonic acid respectively, as

$$1 : 2.05 : 1.04$$

9. The ordinary gunpowders contain more carbon and sulphur than is required by equation (IV).

This excess of carbon and sulphur is left free at the end of the first stage of the combustion.

The free carbon now acts according to equation

$$4K_2SO_4 + 7C = 2K_2CO_3 + 2K_2S_2 + 5CO_2 \quad . \quad . \quad (VI)$$

the free sulphur upon the potassic carbonate as follows:

$$4K_2CO_3 + 7S = K_2SO_4 + 3K_2S_2 + 4CO_2 \quad . \quad . \quad (V)$$

and both united form the second stage of the combustion. These reactions are endothermic; heat is not evolved but consumed; they are not of an explosive nature, and in practice are probably seldom complete.

The reactions of this second stage increase the volume of the gas formed during the first stage of the combustion and diminish the temperature of the products. A portion of the carbonic oxide is formed during the second stage by the action of free carbon or potassic disulphide upon carbonic acid.

10. The reactions represented by equations (III), (IV), (V), and (VI) can be expressed by one equation. If x, y, and z are positive numbers, and a indicates how many molecules of carbonic oxide are formed by the combustion of a weight of powder, containing x molecules of saltpetre, y atoms of carbon, and z atoms of sulphur, the

following will be the general equation representing the complete chemical metamorphosis of powder:

$$\left.\begin{array}{l} xKNO_3 \\ +yC \\ +zS \end{array}\right\} = \left\{\begin{array}{l} \frac{1}{28}[4x+8y-16z-4a](K_2CO_3) \\ +\frac{1}{28}[20x-16y+4z+8a](K_2SO_4) \\ +\frac{1}{28}[-10x+8y+12z-4a](K_2S_2) \\ +\frac{1}{28}[-4x+20y+16z-24a](CO_2) \\ +aCO \\ +\frac{1}{2}xN_2 \end{array}\right.$$

11. If $x=16$, and $a=0$, the volume of the gas (V), generated by complete combustion is nearly

$$=\frac{160+20y+16z}{14} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(IX)}$$

and the units of heat, W,

$$=1000[1827.154-16.925y-8.788z] \quad . \quad . \quad . \quad \text{(X)}$$

y signifies in these equations the number of carbon and z that of the sulphur atoms in a weight of powder containing 16 mols. of saltpetre.

The volume of gas becomes greater and the heat of combustion diminishes with an increase of y and z, and *vice versâ*.

The mixture containing

$$16KNO_3+8C+8S$$

produces the greatest amount of heat and the smallest quantity of gas, and the mixture represented by the symbols

$$16KNO_3+24C+16S$$

the largest volume of gas and the smallest quantity of heat.

12. The product E obtained by the multiplication of V and W (equations IX and X) will approximately represent the relative energies of mixtures of various composition.

The mixture represented by the symbols

$$16KNO_3+24C+16\,S$$

is of all the infinite number of mixtures which can transform themselves according to equation (XIII) the one for which E assumes the greatest value. Hence, a powder of this composition possesses the greatest energy.

13. If a mixture of saltpetre, carbon, and sulphur were required which shall possess nearly the greatest energy, and at the same time contain the smallest amounts of carbon and sulphur compatible with this condition, theory would point to the mixture

$$16KNO_3+22C+8S$$

The service powders of most nations fluctuate about

$$16KNO_3 + 21.2C + 6.6S$$

14. Gunpowder, however, does not contain pure carbon, but besides this element hydrogen and oxygen as constituents of the charcoal.

The oxygen is eliminated with a portion of the hydrogen in the form of water, the remainder of the hydrogen remains either free or unites with carbon, sulphur, and nitrogen respectively, producing sulphuretted hydrogen, ammonia, and marsh gas.

The secondary products only amount from 1 to 2 per cent. of the powders.

15. Mining powders contain much more carbon than is required according to equation (XIII). In consequence, the oxygen of the charcoal is not eliminated during the combustion of these powders with hydrogen, as water, but in combination with carbon as carbonic oxide and carbonic acid.

The hydrogen thus left free causes the formation of a comparatively large proportion of sulphuretted hydrogen and marsh gas. The potassic sulphocyanate is also produced in quantities much larger than those formed by the service powders on account of the carbon left free at the end of the combustion. If we neglect these secondary products, then the combustion of mining powder may be represented by the simple equation:

$$16KNO_3 + 28C + 8S = 4K_2CO_3 + 4K_2S_2 + 12CO_2 + 12CO + 8N_2$$

The reactions can also be represented as follows:

$$16KNO_3 + 28C + 8S = 16KNO_3 + 22C + 8S + 6C$$

16 mols. of saltpetre, 22 atoms of carbon, and 8 atoms of sulphur transform themselves according to (XIII) as follows:

$$16KNO_3 + 22C + 8S = 4K_2CO_3 + 4K_2S_2 + 18CO_2 + 8N_2$$

If, now, 6 atoms of carbon act on 6 mols. of CO_2 we obtain

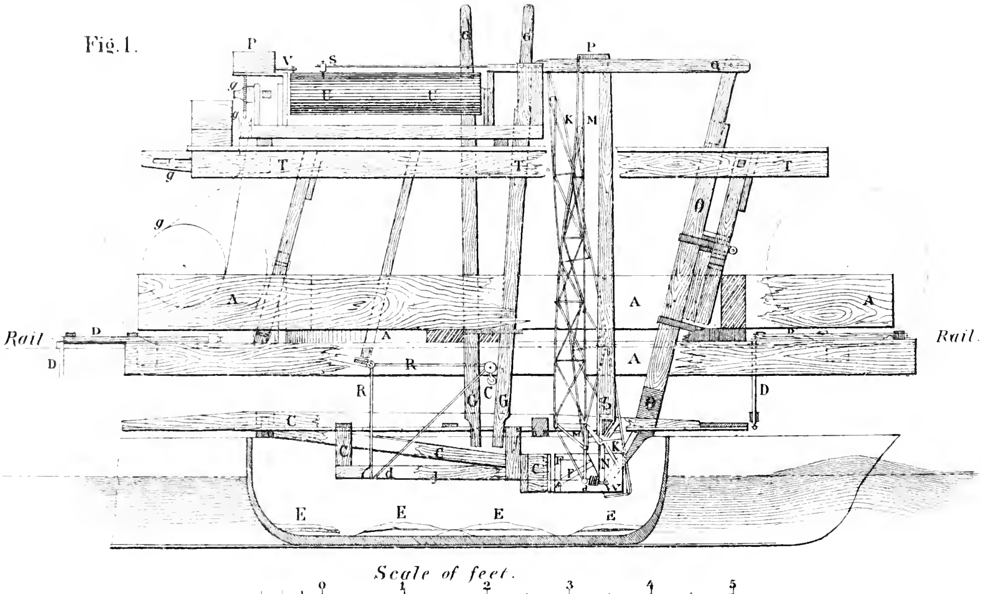
$$6CO_2 + 6C = 12CO$$

In this manner we can conceive the combustion of a mining powder to take place according to the same equations which apply to ordinary gunpowder, and that the excess of carbon in the mining powder causes, subsequently, the reduction of a portion of the carbonic acid to carbonic oxide.

Resistance of Models..

Froude's Dynamometer.

Fig. 1.



I FRIEDENWALD LITH-BALTO.

NAVAL INSTITUTE, WASHINGTON BRANCH.

MARCH 15, 1883.

COMMANDER C. M. CHESTER, U. S. N., in the Chair.

TOWING EXPERIMENTS ON MODELS TO DETERMINE THE RESISTANCE OF FULL-SIZED SHIPS.

By ASSISTANT NAVAL CONSTRUCTOR F. T. BOWLES, U. S. N.

In this paper there is compiled a brief description of Mr. W. Froude's dynamometric apparatus used in towing models, and a description of the method of obtaining from such experiments the resistance of a full-sized ship, and a summary of the most important results arrived at by Mr. Froude.

The tank in which the experiments are carried on is 278′ long, 36′ broad at the top, and 10′ deep.

The framing of the roof, which extends the entire length, carries a pair of rails 40″ apart, and 18″ to 20″ above the surface of the water. The space between the rails is free from sleepers or transverse connections of any kind.

A truck borne by four wheels moves upon these rails, actuated by an endless wire rope, which is driven by a small stationary engine having a heavy fly-wheel and very delicate and easily adjustable governor, invented by Mr. R. E. Froude, by which any speed between 100 and 1000 feet per minute can be given to the truck.

The dynamometric apparatus carried by the truck is illustrated in the outline sketch, Fig. I. The object of this is to measure and record automatically the resistance of a model, and the speed at which it is moving.

The frame *CC* is carried by the model and hung from the truck by the jointed rods *DD*, which allow it to move only in a vertical longitudinal plane, thus allowing the model to change trim, or rise

and fall bodily. This frame is counterbalanced at *W*, so that its equilibrium is practically neutral in all positions.

The resistance of the model is transmitted by the looped link *d* to the spiral spring *N*, which by its extension measures the force. This spring is fixed to the towing beam *O* forming part of the truck, and its extensions are communicated by a system of levers *KK*, *MM*, to an index arm *S*, giving horizontal motion to a pen which registers its position on a sheet of paper wound on the revolving cylinder *u*.

This cylinder revolves at a speed proportional to that of the carriage, the motion being obtained from one of the truck wheels; a second pen actuated by a clock *P* indents the paper at small equal intervals of time, thus recording the speed of the truck.

The scale of resistance is obtained by extending the spring by known weights and recording the extensions upon the cylinder as before.

The models used are made of paraffine, a convenient material; it takes a uniform polish and maintains a clean surface in water. The models are usually made to a length of about 10 feet, though tests have been made upon lengths up to 25 feet. They are shaped by an ingenious machine of Mr. Froude's invention, by which changes in form can readily be made.

We now proceed to describe some of the results obtained by Mr. Froude, whose ingenuity and skill in making and recording the experiment with this delicate apparatus, and eliminating all possible errors, was fully equalled by his wonderful powers of analysis.

By comparison of dynamometric experiments on models of different sizes, and finally by the towing experiments of H. M. S. Greyhound, Froude's Law of Comparison was confirmed, viz. "If the ship be D times the dimensions of the model, and if at the speeds V_1, V_2, V_3, the measured resistances of the model are R_1, R_2, R_3, then for speeds $V_1\sqrt{D}$, $V_2\sqrt{D}$, $V_3\sqrt{D}$ . . . of the ship, the resistance will be D^3R_1, D^3R_2, D^3R_3 . . . To the speeds of the ship and model thus related it is convenient to apply the term "*corresponding speeds*," and this being defined, we may state the scale of comparison more concisely thus: that at corresponding speeds the resistance of the model and ship are in the ratio of the total weights or displacements.

Now the total resistance of a ship at any speed—that is, the towing resistance considered apart from the action or influence of the propelling instrument—is made up of the following elements:

(1) The frictional resistance, which depends upon the area of the

immersed surface, its degree of roughness, and its length, and is not sensibly affected by the form or proportions of the ship.

(2) The eddy-making resistance, which appears in any appreciable amount only in ships of full sterns, and in ordinary cases arises from under-water projections, as shaft tubes and large stern-posts.

(3) The wave-making resistance; this is most influenced by the form and proportion of the ship, in connection with the speed.

The first two elements vary, as we know, approximately as the square of the speed, and this can be easily shown to follow Froude's scale of comparison; but we know that the resistance of ships need not vary as the square of the speed, and, as is shown subsequently in some cases, does vary according to much higher powers; this increase is due to the wave-making resistance, and shows itself at a certain critical speed at which the wave-development becomes marked.

Mr. Froude showed by reasoning from the stream-line theory that the configuration of the stream lines or of the paths of the water around the body was the same for similar forms at all speeds, if totally submerged; but the wave configurations being produced at the surface by a combination of the motion of the stream lines and gravity, these configurations will be similar for similar forms when the additional influence introduced by gravity will permit, and this will be when the velocities are as the square root of the dimensions, for the velocity of similar waves are thus related.

I have thus presented, in a condensed form, the theoretical reasoning which led Mr. Froude to anticipate the truth of the scale of comparison.

It is interesting to remark that this result was reached apparently without the aid of a proposition* in hydro-mechanics known to mathematicians which confirms this reasoning apart from the effect of friction.

In order to verify the law, an extended series of experiments was made on the various elements of resistance. I will briefly describe these, and give the results taken from the Reports of Br. Assoc. 1872 and 1874.

The experiments for frictional resistance were made upon "planes formed of board about 3-16″ thick, 19″ deep, and varying in length from 1 foot to 50 feet, cut-water included," and were connected with the dynamometric apparatus as already described. Along the bot-

* This proposition in its most general form is contained in Routh's Rigid Dynamics, p. 284 *et seq.*

tom of each plane, included in the depth of the 19″, was a lead keel intended to give stability to the plane and to counteract its buoyancy. The planes were made as thin as possible, to have a minimum displacement and present to the line of motion a minimum sectional area as compared with their united surfaces.

This table represents the resistances per square foot due to various lengths of surfaces, of various qualities, when moving with a standard speed of 600 feet per minute, accompanied by figures denoting the power of the speed to which the resistances, if calculated for other speeds, must be taken as approximately proportional.

Under the figure denoting the length of surface in each case are three columns, referenced as follows:

A. Power of speed to which the resistance is approximately proportional.

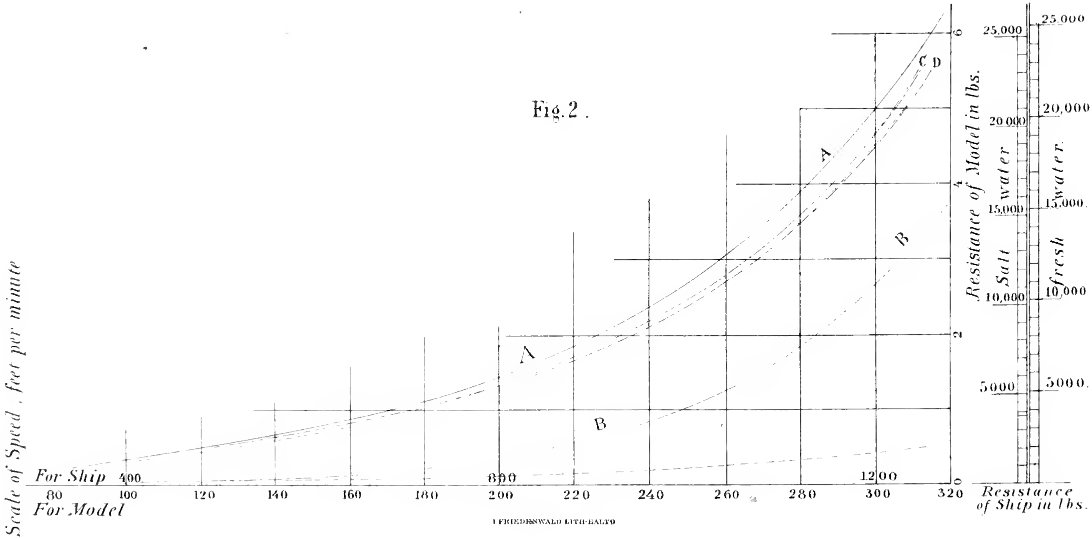
B. Resistance in pounds per square foot of a surface the length of which is that specified in the heading—taken as the mean resistance for the whole length.

C. Resistance per square foot in the unit of surface at the distance sternward from the cutwater specified in the heading.

Nature of Surface.	Length of Surface or Distance from Cutwater in Feet.											
	2 ft.			8 ft.			20 ft.			50 ft.		
	A.	B.	C.	A.	B.	C.	A.	B.	C.	A.	B.	C.
Varnish........	2.00	.41	.390	1.85	.325	.264	1.85	.278	.240	1.83	.250	.22
Paraffine.......	1.95	.38	.37	1.94	.314	.260	1.93	.271	.237	...	...	...
Tinfoil.........	2.16	.30	.295	1.99	.278	.263	1.90	.262	.244	1.83	.246	.232
Calico..........	1.93	.87	.725	1.92	.626	.504	1.89	.531	.447	1.87	.474	.423
Fine Sand.....	2.00	.81	.690	2.00	.583	.450	2.00	.480	.384	2.06	.405	.337
Medium Sand.	2.06	.90	.730	2.00	.625	.488	2.00	.534	.465	2.00	.488	.456
Coarse "	2.00	1.10	.880	2.00	.714	.520	2.00	.588	.490	...	...	...

From this table we see that the frictional resistance generally varies in a ratio rather less than the square of the speed, that there is a great increase in frictional resistance for a comparatively small change in the degree of roughness; thus the coefficient for unbleached cotton is nearly double that of varnish, which is equivalent to a surface of clean paint, or compositions used on ships' bottoms; and the great differences in the mean resistance per square foot for different lengths of surface; thus comparing planes of 2 feet and 50 feet, the mean resistances per square foot are for varnish .41 and .25, and for fine sand .81 and .405 respectively.

Fig. 2.



I FRIEDENWALD LITH-BALTO

This is explained by Mr. Froude as follows: "The portion of the surface that goes first in the line of motion, in experiencing resistance from the water would in turn communicate motion to the water in the direction in which it is itself travelling; consequently the portion of the surface which succeeds the first will be rubbing not against stationary water, but against water partially moving in its own direction, and cannot therefore experience as much resistance from it." This, as we shall see, is important in obtaining the resistance of a ship from the model.

It is interesting to note that this varnished surface gave results equal to a surface coated with smooth paint or composition commonly used on the bottoms of iron ships. The frictional resistance of such a surface moving at a velocity 600 ft. per minute would be about one-quarter pound per square foot of immersed surface, which would give a frictional resistance of about 1 lb. per square foot when moving at a speed of about 12.8 knots per hour.

With regard to eddy resistance the formula used for a plane surface is approximately: Resistance in lbs. $= 1.12\,V^2 A \sin \phi$, where $V =$ speed in feet per sec., $A =$ area of plane in square feet, $\phi =$ the angle of the plane to line of motion. Thus for an area of 1 foot moving normally at speed of 10 feet per sec. the resistance would be 112 lbs.

Wave resistance can only be ascertained by direct experiment.

To obtain the resistance of the ship from that of the model. By means of the dynamometer we obtain the resistance of the model at certain speeds, and these laid off with ordinates speed and resistance in lbs. give the curve of resistance $A\,A$ (Fig. 2) of the model. Now if the law of comparison were exactly true we should only have to alter the scales of the ordinates by dividing the unit of speed by $\sqrt{D}$, D being the ratio of dimensions, and dividing the unit of resistance by D^3, but as the surface of the ship is much larger than that of the model and of different roughness, we must correct the part of resistance due to surface friction. Thus the surface of the model having been accurately found, we estimate the friction at various speeds, and deducting it from the ordinate of $A\,A$ obtain the curve $B\,B$, representing the remaining part of the resistance. We now calculate the frictional resistance of the ship, and on the proper scale add it to the ordinates of $B\,B$, and thus obtain the curve $C\,C$ or the curve of resistance of the ship as deduced from the model.

$D\,D$ is the actual curve of H. M. S. Greyhound, the result of the

towing experiments upon this full-sized ship as given in *Trans. Inst. Naval Architects*, 1874, and as shown, agrees almost exactly with the curve obtained from the model.

From this we can calculate the effective horse power with any speed, thus $\text{E. H. P.} = \frac{\text{Resistance in lbs.} \times \text{speed in ft. per min.}}{33000}$

For the Greyhound at about 10 knots the $\frac{\text{E. H. P.}}{\text{I. H. P.}} = .42$. Mr. Froude assigned the values .37–.40 as average values for single screw steamers at full speed. But this has been much exceeded by the fine formed transatlantic steamers built within the last five years, and by the latest turn-screw ships in the English navy, .48–.52 having been obtained.

I have calculated here, as a matter of interest, the ratio of the frictional to the total resistance of the ship.

Speed.	Total resistance in tons.	Per cent. of resistance due to friction.	Power of speed to which resistance is proportional.	Ratio of resistance to displacement.
4	.6	.95	2.09	
6	1.4	.87	2.09	
8	2.5	.73	2.09	$\frac{1}{470}$
10	4.7	.60	2.8	$\frac{1}{250}$
12	9.0	.43	3.5	$\frac{1}{130}$

I shall now introduce one or two examples of speed curves in order to show the practical application of this experimental work.

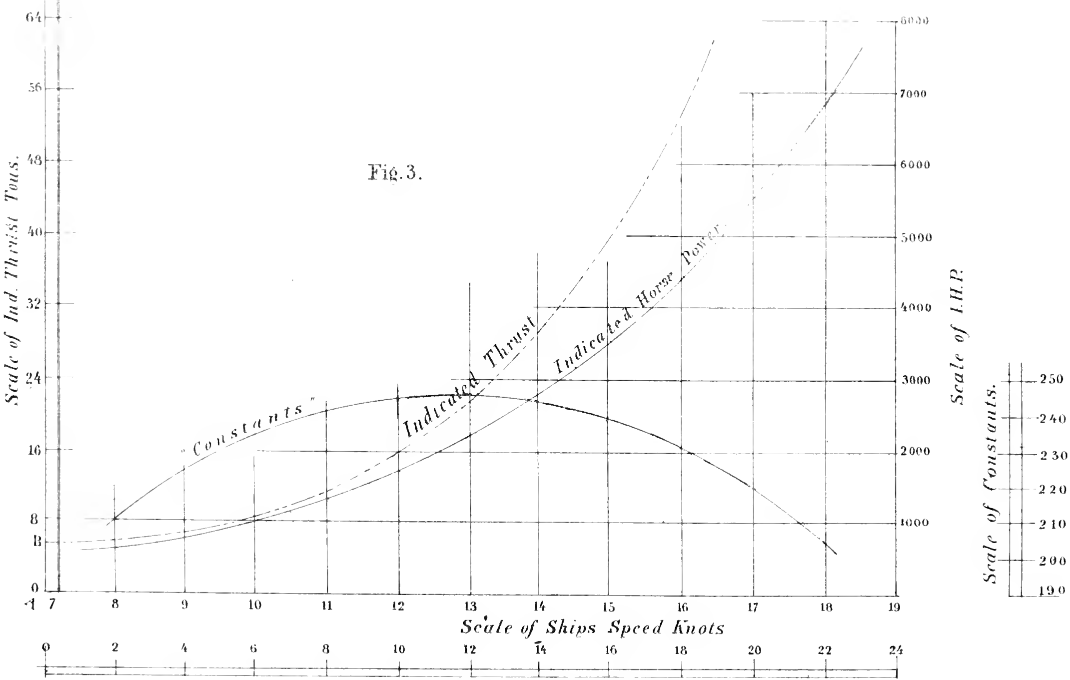
As an example of the application of this law of comparison and a curious case in which the resistance of a large and of a small ship at the same speed tend to become equal, is the following taken from Mr. Froude's paper on "Useful Displacement of Ships."

If R_1 = resistance of small ship at V knots per hour, then R_2 = resistance of large ship which is D times the dimensions of the small one at $V\sqrt{D}$ knots $= R.\ D^3$.

Now, if the resistance of the small ship varies as V^{2+n} then at a speed $V\sqrt{D}$ its resistance will be $R_1\left(\frac{V\sqrt{D}}{V}\right)^{2+n} = R.D^{\frac{2+n}{2}}$

And hence the resistance of the large ship at speed of $V\sqrt{D}$ knots is to the resistance of the small ship at the same speed in the ratio $\frac{R.D^3}{R.D^{\frac{2+n}{2}}} = D^{\frac{2+n}{2}}$ and if $N = 4$ their resistances are equal.

Fig. 3.



I FRIEDENWALD, LITH BALTO.

Speed curves, as of course you are aware, are obtained by progressive trials of ships upon a measured mile, that is, each spot on the curve is the result of generally four runs back and forth across the mile, the turns being made at the same speed, and the revolutions of the engine being kept as nearly as possible constant. The engine counter is noted going on and off the mile, and indicator diagrams taken as rapidly as possible. Their data when worked up give one spot on the curve; others are obtained in a similar way at different speeds and powers.

The curve given in the diagram (Fig. 3) is that from H. M. S. Iris, taken from Mr. Wright's paper on Steam Trials of Iris, *Transactions Institute Naval Architects* for 1879. The curves shown there were obtained with great care, in order to determine the efficiencies of different screws, and are very instructive.

As a matter of interest I have calculated the powers of the speed at which the I. H. P. varies at different speeds, and have also shown the curve of indicated thrust obtained thus:

$$\text{Indicated thrust} = \frac{33000 \times \text{I. H. P.}}{\text{Pitch of screw} \times \text{revolutions per minute.}}$$

Speed.	Power at which Ind. Thrust varies.	Power at which indicated horse power varies.
4	2.3	
6		
	2.5	
8		
	2.5	2.5
10		
	2.5	2.9
12		
	2.5	3.2
14	2.6	3.4
16		
	2.9	3.7
18		

Each ordinate of this curve* is proportional to the mean pressure on the piston at the corresponding speed. This curve we see does not come to zero where the speed is nothing, but the remainder *A B* represents the work done in overcoming the constant friction of the mechanism; and hence, if we measure from a line through *B*, we get our ordinates which are approximately proportional to the actual thrust, this being greater than the towing resistance by the augmentation due to the screw, and including the work lost in the variable friction or that due to the load, the oblique action of the screw, &c.

* NOTE.—An actual ordinate of this curve is obtained for the lowest speed at which the ship is tried, and the remainder is constructed according to the parabolic method given in Mr. Froude's paper on Pitch Slip and Propulsive Efficiency.

We thus obtain a comparative curve of resistance of the ship. By comparing these curves with the curve as obtained from the model we obtain the ratio of the modified thrust to the towing resistance or the effective H. P. with the I. H. P., and hence obtain a coefficient which may be used in similar ships to estimate the I. H. P. required for a given speed.

Mr. Froude did actually experiment with models carrying a screw behind, turned by apparatus carried by the dynamometer, in order to measure the augmentation of resistance due to the action of the screw.

One of the most important uses of the law of comparison is in calculating the speed and corresponding power required for a ship which is to be similar in form but of different dimensions from a given ship for which we have a speed curve and a curve of indicated thrust as shown for the Iris. Using this as a curve of resistance by measuring from a base line down through the point where the curve cuts the zero speed ordinate, we can calculate the resistance for corresponding speeds of the new ship, and thus construct a new curve of indicated thrust. This method is extensively employed among naval architects.

In making these comparisons, it should be remembered, however, that the modified curve of indicated thrust contains elements mentioned above which vary with the type of propulsive machinery.

Another useful result of this law is that it may be easily shown that what is known as the displacement coefficient $(\text{Speed})^3 \times \text{Disp.}^{\frac{2}{3}} \div$ I. H. P. is constant for similar ships of corresponding speeds. It is very common to use the so-called constants, the preceding and $(\text{Speed})^3 \times$ area Midship section $\div$ I. H. P. in estimating power for new ships, therefore I have shown a curve on Fig. 3 which gives the displacement constant for each speed of the Iris, and we can readily see how far from constant it is.

As to the practical value of a model tank it must not be supposed that it will enable us to discover the form of least resistance, because even if such a form existed, many conflicting conditions which must be attended to in a design would limit its application; therefore in these experiments we seek only to determine a form of least resistance compatible with the governing conditions.

Apart from this, our lack of experience in the U. S. Navy with modern ships entails great uncertainty in obtaining desired speeds, and emphasizes the advisability of experiments.

The Admiralty Experiments Works at Torquay are constantly busy.

The Dutch have such an establishment at Amsterdam under the direction of the distinguished Dr. Tideman, Chief Constructor. I

have understood that the Russians constructed an apparatus after Mr. Froude's model. The French are supposed to conduct such experiments at Brest, and the well-known firm of shipbuilders on the Clyde, Messrs. Wm. Denny & Bros., have lately built for their sole use the best equipped experimental tank now existing.

I wish now to go slightly outside the scope of this paper to make a few remarks concerning measured mile trials. Let me say in the beginning that in advocating such trials I think they must be entered upon with a true spirit of scientific research, and not for claptrap or to form a complimentary page in King's or Brassey's compilations. There is considerable to be said on this question, and though I cannot go as fully into it as it deserves, it may be safely stated that it is the only way of obtaining any satisfactory and reliable information of the results and efficiency of the propelling apparatus. Consider how much instructive data was obtained with the trials of H. M. S. Iris, as given in *Transactions* of 1879, and the faults in her screws, determined to a great degree of accuracy.

Upon a measured mile trial of comparatively short duration we have it in our power to make the conditions of trial in regard to coal, state of sea, efficiency of the firemen, and uniform care in registering the results and observations, as nearly as possible the same for all ships, and thus have a degree of comparison which can never be obtained from sea trials or the records of the log, where some piece of information important to the naval architect, for instance, the exact draught of water, is sure to be lacking.

Measured mile trials are continually sneered at as "spurts," the result of "bottling up," and because ships do not make their trial speeds at sea on long voyages.

A ship at sea does not maintain her speed because the power is not maintained, and it cannot be expected that on long voyages the same work can be got out of the boilers and machinery as when every part is in the best possible condition and managed by picked men. In fact, if 75 per cent. of the maximum power is maintained, the result may be considered very satisfactory. Special means, for instance air-tight fire-rooms and forced blast, should be provided for working up to the full available power.

But apart from this, the question is to obtain a correct relation between the power, consumption of coal, and speed, and it is now widely recognized that the only results that can be reasonably trusted are those obtained from systematically and well-conducted measured mile trials.

DISCUSSION.

LIEUTENANT T. B. M. MASON.

Mr. Chairman:—I have listened with great interest to the remarks made to us this evening, and am particularly pleased to hear speed trials over the measured mile so ably advocated. Many officers ridicule the results of such trials because they are never duplicated on service. Such is undoubtedly the case, because the conditions are never again exactly the same. A moment's thought shows us that the same argument would hold good against any other trial. That this latter is the case can easily be shown by the very different speeds attributed in different official reports to the same vessel. In all comparative measurements there must be a standard unit; if there is none we have no starting point for the comparison. The unit for comparisons of speed must be either one of time or of distance.

If the measured mile is adopted, the comparison is made between the times required by different vessels or the same vessel under different conditions to accomplish the run.

If the hour trial is adopted, the comparison is made between the distances run by different vessels or the same vessel under different circumstances in the specified time.

The results of either of these trials, if carefully made, are of the greatest value to the naval architect, and serve as relative figures of merit between vessels, or different modes of running the same vessel.

There is another series of trials which I should have liked to have heard something about in connection with those over the measured mile. I refer to the turning trials of ships, which give results equally important for the study of the naval architect. In order that accurate results may be obtained for comparison between ships and steering gear it is absolutely necessary that these trials should be made under exactly similar circumstances, and that the ship should be uninfluenced by current, wind or sea.

Trials of speed and turning should be made on service under all the varying circumstances of a cruise, and the results of these trials should be tabulated for the use of those who are called upon to handle the ship, and should be reported in order that they may be compared with the results obtained under the most favorable circumstances for the study of the naval architect.

The towing tank advocated by our lecturer would soon pay for itself many times over in providing a practice ground for inventors, thus saving the government the cost of building ships on untried models.

P. A. ENGINEER JOHN C. KAFER.

Mr. Chairman:—I desire to express my high sense of the value of the paper just read, and to no one person are we more indebted for what knowledge we possess of the resistance of ships than to Wm. Froude. By the result of *his* experiments and reasoning the theories formerly advanced have fallen into

disuse. The old mid-ship section and displacement two-third power formula, with their constants, have been laid aside, and when making the computations for the power required to drive new ships—having the drawings only, and not the models—we must use either the augmented surface rule, or calculate separately the frictional, wave-making and eddy resistances. The frictional resistance is very easily calculated, and with well-shaped ships it forms at low rates of speed the chief resistance, but at the higher speeds, and with mis-shapen vessels, we find that the power expended in producing waves and overcoming the resistance due to eddies is a large percentage of the useful power. These two elements of the resistance of ships are of such a nature that it is almost impossible to make any correct calculation of the resistance of an intended ship.

But when we have fully proved the accuracy of Froude's law of comparisons (and I may say that this law is generally admitted to be correct by the majority of persons whose business it is to calculate the power required to drive a vessel a given speed, though not fully proved to be so), and having a machine such as has just been described, then we can get at the resistance of a ship with almost an absolute certainty. But this resistance, in the case of the Greyhound, was about 40 per centum of the indicated horse power developed by the engines to maintain the same speed. The resistance taken in the Greyhound experiments was tow-rope resistance, and not the thrust on the propeller shaft; and as there is such a vast difference between the indicated horse power developed to drive a ship, and the power necessary to tow her at the same speed, which is not satisfactorily accounted for to me by Mr. Froude, I hope that some experiments will be made to determine the actual thrust on the shaft and the resistance by tow-rope.

Whatever the difference may be, it can only be caused by the action of the screw in decreasing the actual head of water at the stern, apparently making the ship run up hill.

In a paper by Mr. Froude about 1877, on the effect of a parallel middle body, it was shown that the introduction of the parallel middle body not only increased the resistance due to the friction of the skin, by reason of the added area, but the wave-making resistance was apparently greater. It was probably the same whether the ship was long or short, but in one case the wave generated by the bow passed the ship with the crest under the counter, while if the ship were longer or shorter the hollow of the wave would be in this position.

I am by no means certain that a dynamometer would give all the resistance due to wave-making, if the determination is made from a model and the application made to a full-sized ship; and to determine the effect of the wave crest or hollow on the stern of a ship, the longitudinal change of time should be carefully noted for each speed, and if possible the contour of the wave marked under the counter.

What we need more than anything else are carefully conducted experiments on the disposition of the power of marine engines, in order to form a correct estimate of the relations of the net to the indicated horse power; then, with a

tank and a good dynamometric apparatus to determine. the resistance of models, we can say with some certainty what the speed of an intended ship will be with a given power.

To show that two ships with equally fine lines, to make the same speed, the smaller requires a much greater power, I will take the Iris and the old Wampanoag, now the Florida. The Iris had a displacement of about 3200 tons on her trial, though with everything on board she displaced 3780 tons, while the Wampanoag had a displacement of about 4200 tons. To make a speed of 17 knots the Iris required about 7000 indicated horse power, and the Wampanoag to make the same speed required but 5000 indicated horse power. Surely this difference cannot be due to the fact that one vessel was sheathed with copper and the other had a painted steel surface in contact with the water.

I wish to say a few words about measured mile trials.

If they are carefully and honestly made we can get the absolute number of revolutions of the shaft while the ship has moved a mile at a given speed, and the indicated horse power to maintain this speed; and the measured mile trial has no other value, unless many runs are made at varying speeds in order that a progressive speed curve may be plotted. I think this information of sufficient value to have every ship tried over a carefully measured mile at such speeds as can be maintained for at least 24 hours, with ordinary fuel.

The Iris is credited with a speed of 18.5 knots over the measured mile, but this was done with a displacement of more than 500 tons less than when ready for sea, and burning Nixon navigation coals. I do believe that she can maintain a speed of over 16 knots at sea for 24 hours with ordinary merchantable coal and all her weights on board. The Wampanoag made 17 knots or nearly that for 24 hours, 15 or 16 years ago, and if her hull was sound could in all probability make that speed to-day.

I congratulate Mr. Bowles on his clear explanation of these towing experiments, and I am sure that his paper will be read with great interest. I hope that he will give the Institute at some time a popular paper explaining the rolling of ships, the effect of raising, lowering and winging out of weights.

Assistant Naval Constructor R. Gatewood.

Mr. Chairman:—Mr. Bowles has asked me not to omit a few remarks which I intended to make on matters bearing upon his paper, and as the subject of augmented surface has also been referred to by Mr. Kafer as useful to the naval architect, I will first state as briefly as possible my conception of the use or uselessness of Rankine's celebrated formula. In the first place let us examine what are the grounds on which it rests. The assumptions are (1) that the resistance of ships commonly consists almost entirely of surface friction; (2) that this resistance varies as the square of the speed for ordinary ships' surfaces, and has a value of one pound per square foot at a speed of about ten knots per hour; (3) that the rubbing velocity of the water past the ship is at all points the same as that consequent on the stream-line motion of a perfect fluid past the ship's form; (4) that for purposes of approximation to the mean

square of the rubbing velocity the motion may be considered with sufficient accuracy, as equivalent to stream-line motion, past trochoidal layers corresponding to the water-lines, of maximum obliquity to the line of motion equal that of these water-lines.

To what extent are the above conditions fulfilled in practice? It must be generally admitted that the experimental results obtained by Mr. Froude given in the paper as bearing upon this point are certainly much more applicable than any similar information available to Prof. Rankine when he originated his formula. We will accordingly examine the conditions by the light of these results, although they will be found to break down without their aid.

As to the first condition, if we are content with keeping within its limitations, no fault can be found with it. But as has been shown in the paper, for every ship's form there is a certain speed beyond which the wave resistance asserts itself and increases rapidly over the frictional resistance, and this speed falls much within the limit of maximum speed of any ordinary war-ship. Accordingly we must not attempt to apply the augmented surface method to reasonably *fast* ships.

The second condition we must modify in accordance with Mr. Froude's results as given in the paper. It will be then found that for clean painted hulls or surfaces coated with ordinary ship's compositions, the law of the resistance in terms of the speed is considerably below that of the square, and also that the correct unit is one pound for about 12.8 knots, instead of 10 knots. These two corrections both tend to bring the resistance curve of ships at low speeds—when the resistance is practically wholly frictional—below the corresponding curve as calculated by augmented surface.

The third condition brings us to the vital error in the method—an error in its principle and not its application. Its source is fully expressed in Mr. Froude's words in the paper; in brief, since the water drags the ship backward, it is an immediate consequence of Newton's third law that the ship should drag the water forward. Hence the rubbing velocity cannot be in accordance with the stream lines of a perfect or frictionless fluid past the ship, but must be less. How much less was always a question until the indefatigable Froude investigated this link in the chain of a ship's resistance, and showed what a formidable thing was the *frictional* wake in ships. He proved conclusively that the frictional wake consists of a narrow following stream of velocity increasing from the boundaries towards the centre, where its velocity is always very considerable, amounting in many cases to from six to seven knots in long ships moving at from thirteen to fifteen knots. This result rigidly derived in its general nature from the laws of mechanics and carefully corroborated and quantified by experiment, at once overthrows the augmented surface method on its own assumptions.

We will however continue the examination of its fundamental conditions. The fourth condition, as is of course well known, excludes all bluff ships from the scope of the rule, since their water lines are very different indeed from trochoidal profiles. It may be useful to note as an example, that as commonly determined, the augmented surface of the Greyhound, a full ship,

in her experimental condition was 13,250 square feet, while her actual immersed surface was 7540 square feet, an enormous difference. It may be conceded, however, that Professor Rankine never intended his method to be applied to such round bodies.

We have seen that the method of augmented surface is vitally defective in principle. Some one may still say, "How about the Warrior and other ships for which its results agreed very exactly with practice? No matter how incorrect the theory, if the rule is of practical use, that fact cannot be gainsaid." The facts are these: Since the "coefficient of augmentation" is a function of the form of the ship only, it is constant at all speeds, and it accordingly follows from what has been said that the corresponding resistance curve of any ship will be a hyperbola, the constant being a resistance of one pound for one square foot of augmented surface at a speed of ship of ten knots. Now we have seen from the paper what is the nature of the actual resistance curve for ships, viz. that at low speeds the resistance is practically frictional only, and as, calculated from Mr. Froude's experimental values, it has a smaller constant and increases at a slower rate than the augmented surface curve. It accordingly falls below the latter for such speeds. But as the critical speed is approached the wave making element appears, causing a resistance the exact law of which varies in differently formed ships, but which is always much higher than the square of the speed. The actual resistance curve therefore, increasing at a more rapid rate, crosses the augmented surface curve at some speed, beyond which it rises much above it. Accordingly, both below and above this particular speed there is a discrepancy between the two, which increases as we recede from it, although the two again coincide at the zero of speed. The difference is of course much greater for a given value above the particular speed than below, which accounts for the marvellous performance sometimes predicated of high speed ships powered by this method.

There is only one more point of interest in this question of augmented surface. Some people profess no confidence in the old displacement and midship-section rules, but still think that in a new design they have something to lean on in the augmented surface method. It may however be simply shown that these three rules must stand or fall together. The displacement rule is:

$$\text{I. H. P.} = \frac{\text{Disp't}^{\frac{2}{3}} \times V^3}{C_1}$$

The midship section rule,

$$\text{I. H. P.} = \frac{\text{Area of midship sect.} \times V^3}{C_2}$$

The augmented surface rule,

$$\text{I. H. P.} = \frac{\text{Augmented surface} \times V^3}{C_3}$$

The curve of constants C_1, C_2 and C_3 must therefore in any case be *identical*, each read to the proper scale. It is shown in the paper how far from constant their values are for the same ship at different speeds, and it immediately follows that none of them can be accurately used except for *similar* ships at *corresponding* speeds, when one is as useful as the others.

I should like to say just a word on the subject of measured mile trials. The full power measured mile run is, as you have remarked, Mr. Chairman, of great use as a basis of performance, both of the same ship under different conditions and of more or less similar ships under the same conditions. A very necessary test of the efficiency of the machinery and boilers in a 6-hour full power run should, however, always be made in this connection.

There is one feature of measured mile trials which I do not think is sufficiently appreciated, or they would invariably be undertaken in all cases. I refer to *progressive* speed trials, such as recorded in the diagram shown by Mr. Bowles of Mr. Wm. Denny's ship, Merkara, and the information to be derived from the curves so obtained. Let us ask ourselves what experimental values are necessary for the analysis of the efficiency of each link in the chain of power, from the pound of coal to the ton weight propelled at a certain speed. The total efficiency will be found to be made up of the following factors:

(1) The efficiency of the boilers, measured in pounds of steam of observed pressure and condition generated per pound of coal burned.

(2) The efficiency of the steam, measured in indicated horse-power per pound of steam passing through the engines.

(3) The efficiency of the mechanism, measured in horse-power delivered to the propelling instrument per I. H. P. exerted by the steam on the piston.

(4) The efficiency of the propeller, in known resistance overcome per H. P. delivered to it at the particular speed. In this is included the effect of augmentation due to the screw.

(5) The efficiency of the ship's form measured by the actual resistance at the given speed.

We have then five links in this chain, of which numbers (1), (2), (and (3) *approximately*) may be obtained by experiment on the motive power according to methods well known to the marine engineer ; (5) can be obtained only from model experiments or by actually towing the ship. Now how is (4), the efficiency of the screw, to be obtained? The answer is, only by a speed curve taken in connection with (3) and (5). Yet this result, it must be admitted, will always be of sufficient value to warrant the comparatively inexpensive experiments necessary, and I venture to recommend the study of the efficiency of the screw propeller under the various conditions of practice as very necessary and as yet comparatively undeveloped, though much expense has been uselessly lavished upon it.

In addition to (4), the curve of indicated thrust obtained from the speed curve gives us the value of (3)—which can also be otherwise approximately obtained as mentioned—as far as the constant friction is concerned, and thus gives us very useful results respecting the efficiency of various types of engines, especially for low speed steaming. Doubt has been cast upon this result, without reason, I think, on account of the great variation observed for similar engines. It need only be mentioned, however, that the tightness of journals and piston-packing, difference in workmanship and finish, and other causes, may seriously influence individual comparisons of constant friction, without affecting averages to any considerable extent.

Allow me once more to reiterate my sense of the necessity of a model tank and properly conducted speed trials for any such naval establishment as this country undoubtedly requires.

I cannot refrain from saying just a word on Mr. Kafer's comparison of the performances of the Wampanoag and Iris. I will say nothing about the actual performance of the Wampanoag, because the exact conditions of the trial as regards wind and tide and such disturbing causes are not known to me. What I do say, however, is that I cannot believe that, under the ordinary conditions of measured mile trials, the Wampanoag could or can make seventeen knots with 5000 I. H. P. Such a performance is so far above anything heretofore obtained, and the Wampanoag's lines are, in my humble opinion, so far from the best possible, that I am not willing to believe that the nature of sea water and ships' resistances are sufficiently different on the two sides of the Atlantic to render any such results possible. But all this is but an additional plea for measured mile or other trials *under standard conditions.*

THE CHAIRMAN :—Although I have read some of the papers of Mr. Froude on resistance of vessels and models, and have listened with the greatest interest to the paper prepared by Mr. Bowles, I think it hardly possible for one to discuss a subject of which Mr. Froude is so preëminently the master without the considerable study that the writer must have given to it. I rise therefore more for the purpose of asking information on a point upon which I have some doubts, than for discussion.

If Mr. Gatewood will permit me then, I will enquire from him if the "wetted surface" of Mr. Froude corresponds in any way to the "augmented surface" of Professor Rankine?

MR. GATEWOOD (in answer) :—Mr. Froude makes no allowance for augmentation of the velocity of gliding, although it undoubtedly exists to an unknown extent, but has found, after much experience, that it is very nearly correct to consider the actual wetted surface as expanded into a plane of the same length as the ship, and moving with her actual velocity. A little reflection on the effect of this will show some compensation for the apparent disregard of augmentation, because we have now thrown the total area equally under the influence of the higher power of the velocity and unit of resistance at the leading edge and the lower values of the leaving edge, whereas in the actual ship the area exposed to the extreme velocities of rubbing are both less than are given by the plane assumption. The result must be greater than if we applied the observed results of frictional resistance to each longitudinal element of the actual skin supposed moving, as a plane with the ship's velocity. A certain amount of correction is thus virtually made for the unknown augmentation.

F. T. BOWLES: I wish to thank Mr. Gatewood for his kindness in reading the paper and his elaboration of the points it contained, and am exceedingly gratified by the interesting discussion the subject has provoked.

THE CHAIRMAN :—I find I was correct in my impressions, but any one who has attempted to enter into the construction of ships on this side of the Atlantic, where Prof. Rankine's "Augmented Surface" has become so generally adopted,

will find it difficult to persuade himself of the fallacy of his reasoning; and I am glad to find that we still have some support for our belief, for Mr. Gatewood has shown that at some point of the augmented resistance curve can be found the actual resistance curve in contact with it, and this point is probably at about the maximum speed of our vessels.

We have yet to see the time when we shall be called upon to deal with the higher speeds of vessels (I refer to our present naval vessels particularly) under the commonly accepted meaning of that phrase in Europe, consequently we can consider the resistance of our ten knot vessel as following the old rule, and be within reasonable limits of the truth; but as we have wisely come to the conclusion that in the small number of naval vessels we are likely to have the speed is the all-important element, how necessary it becomes to have some other method of demonstrating what results may be expected, than the calculations based on the simple plans of the vessel to be constructed.

It is no doubt correct, as intimated by Mr. Kafer, that Froude's laws are not yet complete as regards all their applications, and had the author lived he might have modified them somewhat himself; but they are based on so much more information than was evoked before his experiments were published, that we are compelled to give up Rankine altogether, or for the higher speeds at all events.

Mr. Kafer has expressed doubts as to whether the dynamometer would give all the resistance due to wave-making, and suggests that the longitudinal change of trim should be carefully noted for each speed and the contour of the wave marked under the counter, possibly when running the measured mile.

For my part I cannot see what laws can be deduced from an experiment of this kind, when performed on one vessel and applied to another of different dimensions. The wave-making power of a ship, as shown by Mr. Scott Russell, is due to the form of the entrance and the run. However the reasoning has been criticized, I think we can safely say that the form of a vessel has a great deal to do with it. Take the Trajano for instance (the Brazilian vessel that was discussed before the meeting some time ago in connection with the paper read by Lieutenant Schroeder): while she might have the same length as a vessel built in accordance with the wave-line theory, yet her form, with run commencing at the bow, did in actual practice cause the wave to follow at a distance of several feet from the stern, while in the other vessel it was under the counter. This, as a matter of course, dropped the after part of the former vessel into the hollow of the wave, making the longitudinal axis of inclination very great, while the wave-line vessel of the same length and running at the same speed had the wave lifting her stern, keeping her on an even keel, or nearly so, and making a profile of entirely different dimensions from that in the other case. I know of experiments of this kind having taken place with poor results.

We are therefore, it seems to me, forced back to the model tank, where we can not only try the different forms of vessels as shown in the model, but can draw the profile of the wave; a difficult matter in actual practice when wind, sea, tide, depth of water and other causes may combine as distracting elements.

I think, as will almost universally be the case, that the production of a paper of this kind before the Institute will bring out some points which shall be of interest to its members, even if the paper is, in itself, technical to such an extent as to preclude our discussing it as the professional does; and in this connection I would refer to the measured mile trial which has been brought up. It is true, indeed, that we must have this basis for comparing the speed of vessels; for the sea trial, while it gives the speed under varying circumstances—information that is very desirable for the commander—will produce no data upon which the architect can base the construction of new vessels, and he, at least in our service, will have to refer to the records of the trials over a measured mile for the information he needs.

This, as we have but few vessels worthy to be put on the measured mile course, will make it more apparent that the model tank, a description of which has been so ably presented to us by Mr. Bowles, will be a most desirable acquisition to our naval establishment, as affording a school for experiments not only for the navy, but for the increased merchant marine which is sure to come, and a most essential acquisition should an increased number of war vessels follow those for commercial purposes.

The question of soft coal, as has been most appropriately introduced to the meeting, is another important matter for us to consider in designing our future ships, and I can but re-echo the sentiments of Mr. Gatewood in hoping that our Advisory Board will take its important features into consideration.

I am sure no commanding officer who has tried it, even as the boilers of our vessels are at present constructed, will hesitate a moment between cleanliness and speed; and if, as has been suggested by Admiral Jenkins, politics shall be opposed to the use of soft coal, we, as a possible interested party in the future, should not fail to urge what we deem to be right.

Whatever results shall follow the production of this paper, I feel assured that all the members will view it as a most valuable and interesting addition to the records of the Institute, and that I express the sentiments of the meeting in presenting its thanks to Mr. Bowles for its contents, and to Mr. Gatewood for reading it to us in the absence of his confrere.

NAVAL INSTITUTE, ANNAPOLIS, MD.

MARCH, 1882.

ON THE RELATION EXISTING BETWEEN LENGTH OF BORE AND MUZZLE VELOCITY.

By Lieutenant Chas. A. Stone, U. S. N.

In 1875, the following experiment was made at the National Armory for the purpose of determining the length of bore which gives the maximum muzzle velocity with the Springfield rifle, using the service ammunition. A rifle was made so that the length of bore could be increased from five inches to one hundred and twenty-two inches by additional barrels. The muzzle velocity was measured with each length of bore, each muzzle velocity being the mean of ten shots. The ammunition was, of course, the same throughout the experiment. The following table, taken from the report of the experiment, Army Ordnance Notes No. XXXVIII, shows the lengths of bore and corresponding muzzle velocities:

Lengths of Bore. Inches.	Muzzle Velocity. Feet.
5.	704.
12.	1100.
22. (Carbine).	1210.
26.	1254.
32.6 (Service rifle).	1320.
42.	1345.
62.	1397.
92.	1416.
102.	1410.
112.	1420.
122.	1411.

In order to find the length of bore corresponding to the maximum muzzle velocity, I tried to find a function which would satisfy the

values given in the table. Calling the muzzle velocity v and the length of bore x, the following form was first tried:

$$v = a + bx + cx^2 + fx^3.$$

The values of the constants a, b, c and f were determined from the values of x and v given in the table by the Method of Least Squares. The values of v were then calculated for the values of x given in the table, and the calculated and measured values were compared, but the agreement was not sufficiently close to warrant the use of this form. The form $v = e^{a + bx + cx^2}$ was then tried in the same way. It more nearly satisfied the conditions and showed that this form was better adapted to the purpose than the preceding one, but the differences between the calculated and measured velocities were still too great to make it of any use as an empirical formula. The values of the constants are $a = 6.5867$, $b = .02175$ and $c = -.0001421$.

The calculated and measured velocities are compared in the following table:

Lengths of Bore. Inches.	Muzzle Velocity. (Calculated.) Feet.	Muzzle Velocity. (Measured.) Feet.	Diff's. +	Diff's. —
5.	806.	704.	102.	...
12.	923.	1100.	...	177.
22.	1093.	1210.	...	117.
26.	1160.	1254.	...	94.
32.6	1268.	1320.	...	52.
42.	1408.	1345.	63.	...
62.	1618.	1397.	221.	...
92.	1612.	1416.	196.	...
102.	1521.	1410.	111.	...
112.	1395.	1420.	...	25.
122.	1243.	1411.	...	168.
			+693.	—633.

In order to make the agreement closer another term was added to the exponent, so that the form was

$$v = e^{a + bx + cx^2 + fx^3}.$$

The calculated curve has now two maximum ordinates. The minimum between them was found in the neighborhood of 102 inches, due apparently to the fact that the measured muzzle velocity for 102 inches is less than that on either side of it. This, of course, is an accidental

error, and it would seem to preclude the use of any equation of as high a degree as this unless we reject the result for the length of bore of 102 inches. This minimum is magnified in the calculated curve and the maximum ordinate between it and zero is found between 42 and 62 inches; so that the agreement is not as good as with the previous equation of a lower degree.

The next form tried was one deduced from Sarrau's formula for the muzzle velocity, which, considering all the quantities constant except the muzzle velocity and length of bore, can be written

$$v=\frac{1}{a}x^{\frac{4}{10}}\left[1-bx^{\frac{1}{2}}\right].$$

The constants a and b were determined, as before, by the Method of Least Squares, and were found to be $a=.0021869$ and $b=.050552$. The following table gives the calculated and measured velocities:

Lengths of Bore. Inches.	Muzzle Velocity. (Calculated.) Feet.	Muzzle Velocity. (Measured.) Feet.	Diff's. +	Diff's. —
5.	772.	704.	68.	...
12.	1019.	1100.	...	81.
22.	1201.	1210.	...	9.
26.	1249.	1254.	...	5.
32.6	1311.	1320.	...	9.
42.	1371.	1345.	26.	...
62.	1434.	1397.	37.	...
92.	1437.	1416.	21.	...
102.	1423.	1410.	13.	...
112.	1404.	1420.	...	16.
122.	1380.	1411.	...	31.
			+165.	—151.

This agreement is much closer than with any of the preceding forms, although this one contains but two constants. The fair agreement throughout such a great variation in length of bore confirms, as far as this experiment goes, the employment of this function to express the relation between length of bore and muzzle velocity. From the manner in which it was determined we should expect that it would agree better than a purely general form, but how much better can only be determined by applying it to the results of experiments such as this.

From the formula

$$.0021869v = x^{\frac{4}{10}}\left[1 - .050552x^{\frac{1}{2}}\right]$$

the maximum muzzle velocity is found to be 1446 feet, corresponding to a length of bore of 77.3 inches. The form $v = e^{a + bx + cx^2}$ gives the position of the maximum ordinate nearly the same, namely, at 76.5 inches, but the corresponding muzzle velocity is too great. Since the acceleration is zero where the muzzle velocity is a maximum, this value of $x = 77.3$ inches marks the point at which the remaining pressure of the powder gas on the bullet is just equal to the friction in the bore.

Many other deductions could be made from this empirical formula, but they involve either the supposition that the curve represents the relation between v and x far beyond the values by which it is determined, or the taking of successive derivatives which may depart widely from the truth.

NAVAL INSTITUTE, ANNAPOLIS, MD.

MARCH, 1883.

THE BELLEVILLE BOILER.*

REPORT OF THE BOARD OF INSPECTION ON THE STEAM APPARATUS OF THE DESPATCH BOAT VOLTIGEUR (REAR ADMIRAL HALLIGON, PRESIDENT).

Translated by PROFESSOR J. LEROUX, U. S. N. A.

Description of the Boilers.

The last government vessel fitted with boilers (Belleville system) was the gunboat l'Epée, in 1872. Since that time the Belleville steam-generators have received many improvements. The engine of the Voltigeur contains them all, and therefore differs considerably from the apparatus of the same system previously introduced into the navy, and deserves on that account a complete description.

Grouping of the Boilers.

There are six boilers identical in shape placed back to back, three on each side of the midship line of the vessel, the whole occupying an area 16.404 ft. long by 11.483 ft. wide.

The height of the generators is 10.171 ft. above the floor, with a mean distance of 13.78 in. from the deck-beams above.

There are two fore and aft firerooms on the port and starboard sides of the ship respectively, connected by a transverse passage two feet wide.

* This boiler, similar in principle to the Herreshoff, is being tested in the French Navy in large vessels. The accompanying report and other information relating to it (see Proc. Vol. VIII, No. 4, p. 693) is furnished the Naval Institute, by the manufacturers, MM. J. Belleville et Cie, St. Denis, France. The report is slightly abridged.

Partitions and Shells of the Group of Boilers.

Each group of boilers is encased in a shell whose vertical sides are formed, to the height of the grate, by sheet-iron, to the bottom of the tubes, by fire-bricks, and to the top of the tubes, by sheet-iron. The partitions between the middle boilers are of a single sheet-iron plate 0.315 in. thick, but those encasing the outside of the group consist of two plates with an intervening space of 1.378 in. filled with a non-conducting layer of fine, well-beaten coal-cinders; they have besides a third sheet-iron plate forming an air-casing. The shells are joined on top by a double casing of sheet-iron filled up with coal-cinders.

Boiler Attachments.

As above stated, the six boilers are identical in form, and constitute as many independent generators. Each boiler is composed essentially of:

1. A tubular nest divided into five distinct elements constituting the steam generating apparatus proper.

2. A steam collecting purifier placed on the upper part of the tubular nest, and serving on one hand to collect and dry the steam before its passage to the engine, and on the other hand to free the feed-water flowing through it from the impurities it holds in suspension or in solution.

3. A feed collector at the bottom of the tubular nest furnishing water to the different elements.

4. A self-acting feed regulator.

5. A receiver for ejecting into the sea the deposits caused by the feed-water.

The tubular nest set over a furnace occupying the whole base of the shell, is alone exposed to the action of the gases of combustion; all the other attachments being outside the shell.

Combustion Furnaces.

The combustion of coal takes place in a rectangular furnace 4.593 ft. wide by 4.724 ft. long. The distance from the base of the tubes to the grate is 21.65 in. at the front, and 23.622 in. at the back.

The capacity of the furnace is 38.141 cu. ft.

The sides of the furnace are built of fire-bricks up to the tubular boiler. Originally the width and depth of the grate were the same

as that of the furnace; but as a result of the primary tests it was found expedient to reduce its surface by a stationary line of bricks five inches wide at the back and sides, laid flat on the bars, and removable at will. The surface of each grate has thus been reduced to 15.177 sq. ft. and the total surface to 91.07 sq. ft., a reduction of 24 per cent. from the original surface.

The slope of the grate is one inch in twenty. The bars, numbering sixty, have a peculiar shape, consisting of iron blades of an average thickness of .4 in. and 4 in. high, presenting, lengthwise, a series of regular undulations with an amplitude of .4 in. in height and 4 in. in length. The ratio of clear space to the total surface is exactly one-half. The maximum space between bars is .8 in. Originally there were straight bars alternating with undulating ones; the grate was then more compact, and the ratio of clear space to the total surface was one-third. The air passages were found insufficient and the straight bars were removed. This arrangement of the grates has been devised 1st, to allow the passage of but few cinders, the clear space between the bars being very narrow; 2d, to obtain a uniform temperature for all the bars, by the multiplicity and extent of contacts; 3d, to cool the grate and heat the inflowing air by means of deep bars; 4th, to preserve the grate, and avoid at the same time local overheating and reddening of certain bars, and consequently allow only a feeble adherence of the clinkers.

Owing to the great width of the furnace it was found necessary to provide it with two doors, each door being 15.75 in. wide. Each door is made in two sections. The lower section 4.72 in. high, allows the introduction of the slice-bar during the cleaning process. The upper section is used for coaling. The two furnace-doors being never open at the same time, the inflow of cold air so detrimental to the draught and combustion is limited; the working of the fires is facilitated by this arrangement, as the firemen are less exposed to the radiating heat of the furnace, which is all the more intense owing to the fire-brick lining. It should be here stated that when the brick works are heated, the high temperature in the furnace produces very rapid combustion of the fresh coal thrown upon the grate, and permits the use of the hardest kind of anthracite coals.

The above is one of the advantages claimed by M. Belleville in favor of the boilers of his system, compared with boilers having interior furnaces necessitating the use of free-burning bituminous coals.

Ash-pit.

The bottom of the ash-pit is formed by a sheet-iron pan 10 inches deep, containing constantly a certain quantity of water for extinguishing the burning cinders that fall through the grating. To prevent this water from flooding the floor with the rolling of the ship, a piece of angle-iron 3 inches high is fastened in front of the ash-pit; this plate serves at the same time as a buttress for the feet of the firemen. The door of the ash-pit is 16 inches high and 3 feet wide; it swings around a horizontal axis placed a little above the mean height. Between the vertical position corresponding to the close shut and the horizontal (wide open), it may occupy five intermediate positions, in which it is held by means of a notched rack.

In their passage from the furnace to the chimney through the tubular nests, the gases of combustion meet with a series of horizontal plates which force them to make several circuits along the tubes for the purpose of equalizing the heat.

Generation of Steam.

The tubular nest constituting the steam generator proper is composed of five distinct elements placed side by side in the boiler, and communicating with each other only by means of the feed collector at the base and the steam purifier at the top. Each element forms a coil composed of eighteen tubes arranged in two vertical rows of nine tubes each. The tubes of the two rows are connected by boxes at front and back. The lower front box, which is set directly upon the feed collector, receives the first tube of the coil—besides two other tubes; above it are seven plain boxes bearing two tubes each; finally, above the latter is the elbow that receives the last tube and communicates with the steam purifier. At the back of the nest are nine plain boxes receiving two tubes each. The two apertures in each plain box for the fitting of the tubes are in the same horizontal line, but the boxes at the back are mid-height with the boxes in front; it follows that to pass from one to the other the tubes must be inclined. All the tubes of one row of the element are parallel and incline upwards from front to back; those of the other row are also parallel, but incline upwards from back to front. If we follow the course of the coil from the feed collector to the steam purifier, we will find, therefore, a series of tubes placed alternately on each side of the mean vertical plane of the element, and always rising with a regular inclination

of one in twenty. This arrangement, peculiar to the Belleville boilers (model of 1877), constitutes an important improvement upon the preceding types, inasmuch as it increases the evaporative efficiency, allows the free escape of steam from the heated surfaces and thus avoiding the primary cause of overheating, and when the boiler is empty, prevents the local corrosion of the tubes by preventing drops of water from remaining in the nest, as occurs in horizontal tubes.

The tubular nest is supported in front by the feed collector (which itself rests upon the front bulkhead) to which it is secured. In the back it simply rests upon the brick-work, without any bracing; at the top it is fastened to the steam purifier by socket bolts (one for each element). The connecting boxes are separated from each other by means of inserted blocks. In these conditions, the expansion of the elements by the action of the fire remains perfectly free. Besides, it is very easy to separate one element from the rest of the section.

The tubes are screwed into the connecting boxes, being fitted directly into the back connecting boxes and the joint strengthened by a plain ring; the same is done in front, for all the tubes of one row of the elements, with the exception of the lower box and the upper elbow, but in the case of the other row, the connection is made by means of a collar which unites the end of the tube with a nipple screwed into the box and projecting 1.25 in. outside. By cutting this collar or cylinder and the ring that accompanies it, to consolidate the joint, the tube is isolated from the box and the coil is separated into two parts. This operation can be performed at any height of the element.

The tubes are 4 inches in exterior diameter and 0.2 in. in thickness, with the exception of the lower tubes, which, being exposed to the direct action of the fire, have a thickness of .25 in.

The tubes are of wrought iron, lap-welded. One of the tubes was cut during the repair test; it was opened in the plane of one of its generatrices and strips cut, which were then broken with the wrought iron testing machine. The results of the trial were as follows:

	Strips Cut.	
	Lengthwise.	Crosswise.
Breaking strain per sq. in. . . .	54048 lbs.	32287 lbs.
Elongation	20.4 per ct.	1.5 per ct.

These figures place the metal of the tubes nearly on a par with the best wrought-iron; the elongations however are somewhat less.

The connecting-boxes are of malleable cast-iron. They are pierced with holes with cast-iron plugs opposite the tubes, for the purpose of examining and cleaning the interior. The exterior cleaning is done by means of the steam-cleaner and brushes. In order to facilitate this operation, two large doors are fitted in front, covering the whole height and width of the tubular nest. They are exteriorly provided with air casings and wooden lagging to prevent radiation. In normal firing, the level of the water rises in the elements to about the fourth row of the tubes. The corresponding volume of water is 17.163 cu. ft. for each generator, the volume of steam space 21.684 cu. ft. However, as will be seen further on, the water level is subject to sudden fluctuations, and these figures represent only an average.

The heating surface of each generator, including the whole exterior surface of the tubes and boxes exposed to the fire, is 508.98 sq. ft. or 25.8 times the surface of the original grates, and 33.4 times the present surface.

Fusible plugs.—A safety contrivance for warning the fireman of the lowering of the level of the water, or the superheating of the steam, should be here referred to. It consists in fusible tin plugs .2 in. in diameter, driven in the fourth and seventh row of boxes. These plugs melt at 446° F. The moment that the steam reaches this temperature the plugs melt, and the steam escapes with a peculiar hissing sound. When the water-level falls abnormally in the element, the steam in the upper tubes becomes superheated, and the plugs of the seventh row melt away. If one of the tubes of the element gets obstructed, the whole coil becomes overheated, owing to the failure of circulation of the steam, and the plugs of the fourth row are the first to disappear. The melted plugs are replaced without the least trouble and without stopping.

Drying Process, Steam Purifier.

The steam generated in the tubes carries along with it from three to six times its weight of water, the proportion varying according to the activity of combustion. The drying of the steam is therefore rendered indispensable, and is one of the operations performed by the steam purifier.

The purifier is composed of a sheet-iron cylinder 0.47 inch in thickness, 17.8 inches in interior diameter, and 4.364 feet in length, provided at each end with plugs for the purpose of examining the

interior. It rests in a horizontal position above the front boxes of the tubular nest outside the casing, and receives underneath five pipes, each of 2.8 inches interior diameter, which establish communication with the five elements.

At 2.4 inches over the orifices of these pipes is a horizontal sheet-iron plate, riveted on one side to the lateral wall of the collector, and bent on the other side so as to form one-half a cylinder concentric with the purifier, and having a smaller diameter, allowing between the two a passage 1.8 inches wide.

In order to reach the centre of the collector, the mixture, steam and water, issuing from the pipes of the elements, after being projected against the horizontal plate, must follow in an arc of 180° the annular space between the two cylinders, and as it possesses a high speed, the separation of water and steam is done mechanically by centrifugal force. To ascertain at any time when the drying is complete, two test cocks are placed, one at the entrance to the purifier and the other at the exit, which permit of judging by its appearance the state of the steam.

Separator.—The water separated from the steam goes back into the elements. The dry steam, in order to pass from the centre of the collector into the pipe leading to the engine, must go through a cast-iron tube called the separator, 3.346 inches in interior diameter and 2.950 feet in length, into which it enters through three holes 0.472 inch diameter, bored at regular intervals, the three together having an area of 0.525 square inch.* The steam finally issues from the separator through a pipe 2.76 inches in diameter inserted into the collector and connected with the exterior steam pipes. The object of the separator is to equalize the pressure of the different elements of the steam generator. The purifier not only performs the drying operation, it contributes also to the heating and purifying of the feed-water that passes through the whole length of it before it reaches the elements.

The water enters at the right-hand back corner and flows over the floor formed by the upper surface of the horizontal plate before referred to, through the whole length of the purifier, issuing at the other end and passing to the feed collector. During all its course through the steam purifier the feed-water is therefore in direct contact with the steam, and gets rapidly heated, and this sudden increase of temperature causes the precipitation of the salts and other

*This separator is apparently in the longitudinal axis of the purifier.

impurities which it holds in solution or in suspension. These impurities carried along with it into the pipe of the ejecting receiver, are afterwards blown out by simply opening the cocks.

The steam purifier is one of the new improvements of the Belleville boilers; it is an important attachment, as much on account of the steam drying operation that takes place in a sure and regular manner, as on account of the heating and purifying of the feed-water, which exerts a considerable influence upon the working and preservation of the tubular nest.

Feed.—Forced up by the pumps of the engine, the feed-water, before reaching the steam purifier, must pass through a special attachment, the *self-acting feed regulator*, which plays a most important part in the maintenance of the water level in the elements, and consequently in the production of steam.

Apparent Level.

The working of the feed-regulator is based upon phenomena of apparent level little observable in boilers having a great volume of water, but well marked, on the contrary, in boilers of the Belleville or similar systems. In every boiler in active operation the flowing of steam can only take place under the influence of a difference of pressure between the surface of the boiling water and the orifice through which the steam escapes from the boiler. The loss in the load or the diminution in the pressure of this flowing steam from the surface to the orifice is greater for a definite supply of steam:

1. As the rapidity of the flow is more considerable, that is to say, as the diameter of the moving column of steam between the water surface and the orifice is smaller.

2. As the resistances to the flow are greater. These resistances vary directly as the distance travelled and inversely as the size of the tubes traversed, and depend also on the density of the steam, or, in case of mixture of steam and water, on the density of the mixture, which is greater as the quantity of water increases.

From the fact of a difference of pressure between the water surface and the escape orifice, it results by placing alongside the boiler a vertical tube whose lower end enters the water and the upper the steam near the escape orifice, that the apparent level in the tube will be higher than the actual level in the boiler and will exceed it by a quantity which will be precisely equal to the water height corres-

ponding to the difference of pressure at the surface of the water and that caused by the steam flowing out.

If we attach the upper end at different heights in the steam space, the lower end of the tube remaining unchanged, the difference between the actual and the apparent levels will measure the loss of load between the water surface and these different points; it will go on decreasing in proportion as the upper point of attachment approaches the surface of the water.

The difference between the real and apparent levels is easily set off; the apparent level having been marked on the pipe while the boiler is in operation, it is only necessary to shut off the steam suddenly at the stop-valve. The level will then fall instantaneously in the pipe till it reaches the actual level in the boiler. The distance between the two levels thus observed equals the water height corresponding to the loss of load.

The water-pipe is attached, at the lower end to the lower connecting box, and at the upper end to the third box below the elbow coil at the top of the element, the upper end being therefore about half-way between the surface of the water and the orifice of exit. In these conditions the difference between the apparent and real levels is about 5.9 in. in normal firing and 7.9 in. in excessive firing.

Manner of Regulating the Feed.

Let us now suppose that before the entrance of the feed-water into the boiler there has been fixed upon the feed-pipe a self-acting apparatus that hermetically closes the passage, when the apparent level, as shown in the water column, reaches a definite point, which we will call the normal level, and opens only when it falls below this level; the consequence will be that the feed being stopped, whilst the apparent level remains below that point, the real level in the boiler will fall little by little, in proportion to the consumption of steam, until the moment when the apparent level, which follows its motion at a distance, reaches the normal point. The flow of the feed-water will then begin again, the level will become constant and will have thus established itself automatically in the boiler, at a distance from the apparent level, which will represent the loss of load of the outflow. The real level being thus regulated, if the combustion is accelerated in the furnace, and, consequently, the generation of steam increased, causing a greater amount of water to be carried forward with the steam, the resistance to the flow of steam and consequently the loss of load

will be greater, thus increasing the distance between the actual and apparent levels. The apparent level will then rise at first, the feeding will stop, and there will be a progressive falling of both levels until the apparent level returns to the normal point; the relative balance of the levels will then be re-established, but the real level will be lower than it was before. Thus, from the tendency to foam, the real level will have fallen in the boiler. The contrary result would have taken place if combustion had been sluggish, and if there had been a lesser tendency to foaming.

The consequence of these fluctuations of the real level, according to the activity of combustion and ebullition, is that the steam always reaches the collector in the same state of moisture, and if any change should take place in that state the boiler corrects it itself. There is, therefore, established a self-acting regulation of feed whose effect is to maintain constant the initial state of the steam.

Self-acting feed regulator.—The apparatus designed for the foregoing purpose is the self-acting feed regulator. It is essentially composed of a float placed in the water-column. The complete arrangement comprises:

1. The water-column of cast-iron, square section, 3.773 feet in height and 7.086 inches square. To the water-column pipe are attached directly the glass gauge, the gauge-cocks and the manometer gauge, whose mouth is in the water.

2. The float, composed of an iron cylinder 5.5 inches in exterior diameter and 19.685 inches in height, which works a round vertical rod of 0.787 inch, which issues from the water-column through a stuffing-box.

3. A horizontal lever transmitting the motion of the float rod to another of the same diameter bearing the regulating valve.

4. A self-acting cock, composed of a bronze curved tubing, with an interior seat for the regulating valve. The feed-water enters at one end of this tube and leaves at the other, after traversing the passage opened by the valve. The self-acting cock is secured to the water-column.

5. The regulating bronze valve, with conical seat 8 inches in diameter, with a lift of .3 of an inch.

6. A spring and a balance weight placed at the end of the horizontal lever, which together partially balance the weight of the float and its connections. The tension of the spring is steady, but the balance weight is composed of eight leaden disks that can be easily removed.

It must be noticed:

1. That the self-acting cock and the water column are entirely separated. The temperature of the self-acting cock is thus always relatively low; the valve therefore is not warped, and can only become obstructed by the impurities brought in by the feed-water.

2. That the system of levers is so designed that it is perfectly balanced in regard to steam pressure as well as to water pressure. The valve has therefore no tendency to jam, but is regulated exclusively by the float, and is sensitive to the slightest movement.

3. That the stuffing-boxes through which the rods penetrate into the water-level pipe, and the self-acting cock, are packed with anti-friction material, and are therefore very smooth and at the same time very substantial.

It is owing to these precautions that the self-acting feed apparatus possesses an extreme sensibility, while being at the same time free from any uncertainty in its action, which is the common drawback in apparatus of that kind. The inclination of the lever, placed in a conspicuous position, points out the position of the valve, and enables a person to ascertain at a glance if the regulator is in working order.

The eight balance disks of the regulator being in their places, the check valve closes completely when the water reaches a point two-thirds of the height of glass water gauge tube. This point represents the *normal level*. If we remove the eight disks, which produces the same effect as if the weight of the float were increased by a certain quantity (about eight-ninths of the weight of the eight disks), it will require a higher level to close the valve. The normal level will therefore be raised and with it the real level in the boiler; consequently we will obtain in the steam purifier steam more saturated with water. Thus, by removing one or more disks we displace at the same time both the normal and real levels, and we modify the state of the steam.

Course of the feed-water.—After issuing from the feed-pumps of the engine the feed-water passes first through a rose pierced with very fine holes, intended to prevent the impurities from reaching the apparatus of the regulators. It then passes through the pipes to the base of the boilers.

The special branch pipe of each generator leads to a graded cock, which is worked by hand, and is intended, by partially cutting off the flow of water, to relieve the automatic valves or to distribute the water equally among them when from any reason the check-valves happen to be wide open. Over the graded cock is a valve closing from the

inside, to prevent the return of water from the generator in case of a break in the feed-pipes. This valve is indispensable, the self-acting valve being balanced.

The water reaches then the automatic regulator and thence passes into the steam purifier; there it is heated, the impurities it holds in suspension or in solution are precipitated, leave the purifier with it, and follow it in the vertical pipe of the *ejector*. This pipe occupies the whole height of the tubular nest (outside the shell) and is continued by the ejector proper. The latter supports at the height of the lower coil boxes a horizontal tube, which connects with a wrought-iron rectangular tube 4.92 inches by 5.315 inches on the sides and 4.363 feet in length.

Feed-collector.—This tube is the feed-collector. It supports the twin boxes of the elements, and is connected with them by means of pipes with conical joints, which extend into the boxes through cast-iron nipples, which raise the inflow orifice of the feed-water above the bottom of the box and prevent its being obstructed with sediment. Four removable plugs facilitate the examination of the interior of the collector; a blow-off or drain-cock serves to empty it.

It has been seen that the feed is regulated automatically, not only according to the quantity of water contained in the generator, but also according to the state of the steam; that is to say, the real level in a boiler undergoes continuous fluctuations, according to the degree of activity of ebullition and combustion.

Supplementary Cistern.—The volume of the wells of the condensers and of the safety discharge-pipes, which are an immediate continuation, is too small to meet these fluctuations, and there would have been some danger of the condensed water being frequently ejected into the sea through the discharge-pipes, if there had not been provided a supplementary cistern consisting simply in a large tub, with a capacity of 1800 litres, placed under the flooring of the engine and connected by a special pipe with the horizontal branch of the safety discharge-pipes.

Blowing-out Ejector.—It has been seen that on leaving the steam-purifier the feed-water, in order to pass into the feed-collector of the elements, follows a vertical pipe with a box extension; this box forms the ejector. The pipe is of wrought-iron, its interior diameter is $3\frac{1}{2}$ in. It is connected by a malleable cast-iron elbow with the ejector; this is composed of a sheet-iron cylinder 7.87 in. in interior diameter and 35.433 in. in length. The pipes connecting it at its upper part with the feed-collector are of malleable cast-iron.

The ejector has a blow-off cock placed 10 in. from the base extending internally through a tube pointing downwards, which terminates at 5.906 in. from the bottom, and externally through a pipe which connects with the main blow-out pipe. It is, besides, provided with a cleaning digestor and a blow or drain cock.

The working of the ejector is very simple; during the passage of the feed-water in the steam purifier, the impurities which it holds in suspension or in solution are separated in a pulverulent state; they are precipitated during the flow of the water in the vertical pipe and fall to the bottom of the cistern, from which they are removed by the blow-off cock into the sea. The water flowing into the collector is therefore pure and clear.

Steam-pipes.

Each one of the steam purifiers has a steam-pipe connection forming a continuation of the pipes of the separator. From these proceed pipes 2.165 in. interior diameter, which unite with the main steam-pipe 6.7 in. interior diameter that goes from the boiler-room to the engine-room, passing through the starboard alley.

General Steam Purifier.

Before it reaches the engine the steam passes through the general steam purifier, which is intended to rid it of the water that it might yet contain, produced either by condensation in the pipes or from temporary trouble in the operation of the steam purifiers of the boilers. The main steam purifier, like the latter, dries the steam by centrifugal drying; its arrangements are similar. It is composed of a vertical cylinder 8.55 ft. high and 17.72 in. interior diameter. The steam enters through a tube situated at the top of the cylinder and in the axis; it issues through a tube situated in the upper portion of the cylinder and on one side. It cannot pass from one tube to the other, that is, from the centre of the purifier to the circumference, except by following a leading passage formed by a cylinder internal to the first and broken in a part of its circuit. The annular space between the two cylinders is 2.4 in. in width.

The water separated from the steam falls to the bottom of the purifier, and is expelled by a self-acting "snifter" which drives it into the supplementary cistern. The snifter consists in a float working a cock and balanced by an exterior weight. The cock is entirely outside the purifier. All the stuffing-boxes of the snifter are packed

with anti-friction packing. The purifier has besides a hand-snifter, and is provided with test-cocks for the purpose of ascertaining the state of the steam before and after the drying operation.

After issuing from the general steam purifier the steam traverses the valve-box of the throttle-valve, and finally reaches the main stop-valve-box, which permits the absolute shutting off of all communications between the boilers and the engine. At this stop-valve-box begin the steam-pipes of the engine.

Cleaning the Boilers.

The boilers are easily cleaned: the interior of the tubular nest, by taking out the plugs of the connecting-boxes and applying the tube-scrapers and brushes; the exterior of the nest, by opening the front doors and using first the steam-cleaner, then the brush; the steam and feed-water collectors and the ejectors, by removing the plugs and scaling off with the usual tools.

Trial Trip.—Sea-water Test.

The necessity of the use of sea-water has been foreseen by M. Belleville, and has led to one of the peculiar improvements of the boilers, 1877 model.

The reasons why sea-water is harmless to the generators of this type are:

1. The arrangements for precipitating the salts that are insoluble at a high temperature in sea-water (sulphate of lime, &c.), and their blowing out while under way through the blow-off pipes.

2. The fact that the water level can be raised without any change in the state of the steam. The continuous carrying on by the steam of a large quantity of water into the upper tubes of the elements, prevents the deposit therein of any soluble salts. Any accumulation is carried by the water of the steam into the purifier and thence to the ejector.

3. The use of blow-out pipes, properly regulated, to prevent the density of the water in the generators from increasing above a certain limit, in order that there may be no fear of crystallization taking place in the lower tubes.

The trial began at 7 A. M. and lasted till 2 P. M. At 8 o'clock, saturation being over 4.5°, blowing out was commenced. To do this the blow-out cock was opened two or three times in quick succession in order to lower the apparent level by from three to four inches.

The same operation was repeated successively with the six generators. From 8 to 2 it was repeated twenty-four times, or every quarter of an hour on an average. No attempt was made to ascertain what effect this blowing out had on the consumption of coal, the main object being to ascertain whether the boilers would work in these conditions. An examination made two days later did not show any scale to speak of, either in the tubes or in the steam or feed-collectors.

Results of the Official Trials of the Engine of the "Voltigeur."

Nature of the Trial.	Natural draught. All the fires. Fires urged to their maximum.	Natural draught. All the fires. Moderate firing.	Natural draught. All the fires. Normal power.	Artificial draught. All the fires. Fires urged to their utmost.
Date of trial	April 27	April 27	April 30	May 29
Time of trial of consumption of fuel	4h 4m	4h 6m	6h 9m	4h 25m
Cut off from beginning of stroke of piston, middle cylinder	0.65	0.35	0.45	0.70
Opening of stop-valves of boilers	6/12	2/12	2/12	wide
Opening of throttle-valve of engine	wide	1/10	wide	wide
Opening of the valve	wide	1/20	wide	wide
Pressure in boilers, lbs. per sq. ft.	91.1	67.6	87.5	101.8
Pressure at the valve, lbs. per sq. ft.	58.7	57.9	60.4	59.8
Back pressure in the condenser, lbs. per sq. ft.	1.4	1.0	0.97	2.0
Temperature of feed-water	92° F	61° F	84° F	110° F
Heating of circulating water	17.5° F	14.4 F	18.5° F	18.0° F
Number of revolutions—				
Trial of speed	105.4	77.5	98.9	110.1
Trial of consumption	105.3	77.6	99.0	110.1
Developed power—				
Trial of speed (English H. P.)	894.5	357.3	725.6	985.6
Trial of consumpt'n (Eng. H. P.)	888.0	357.9	725.7	986.3
Coal consumed per hour—				
Per square foot of grate, lbs	26.7	8.8	18.2	32.8
Per horse-power, lbs	2.74	2.25	2.29	3.03
Weight of steam per H. P., lbs	20.05	20.07	19.02	...
Vaporization per pound of coal	7.31	8.92	8.30	...
Mean draught in feet	11.54	11.54	11.48	11.28
Difference of draughts	3.47	3.47	3.44	3.50
Immersed surface of midship frame square feet	224.88	224.88	223.5	217.9
Speed (knots ?)	11.85	8.99	11.35	12.48
Recoil (slip ?)	0.157	0.130	0.140	0.149
Utilization	3.37	3.47	3.46	3.40

Raising steam.—Steam was raised in a remarkably short time. Several trials were made with this object in view. By firing the six boilers at the same time steam was gotten up in fifteen minutes. The moment steam is up the engine is blown through. Eight minutes after there are 4 kg. pressure on the valve, and the engine may be turned over. This takes two minutes, and then the engine is ready to start. It takes therefore twenty-five minutes from the time of lighting the fires to start the engine. Fifteen minutes later it may be driven at a hundred revolutions a minute.

These experiments were made with the water-level at the base of the tubes, which is sufficient, requiring, with ordinary firing, 12 kg. of wood and 65 kg. of coal for each furnace. By sprinkling with oil three or four minutes could be gained.

Cleaning of fires.—The peculiar arrangements of the grate answer their purpose satisfactorily; the slag adhering only slightly to the bars, is easily detached. This part of the operation is rendered easy by the lower half-door; the troublesome part is that which necessitates the opening of the upper half-door, and exposes the fireman to the intense heat of the furnace for some considerable time. The cinders are thrown into the ash-pit and removed when cool. When it is proposed to clean all the fires, it is advisable, in order to preserve regularity in the pressure, to do one-half of a furnace at one time, taking each boiler in succession, and when this first half of the operation is ended, then to do the other halves.

Steam purifying.—The attachments for steam drying are ingeniously combined and always worked perfectly. When in the course of ordinary steaming it happened that the steam brought with it a little water in the main pipe, the general purifier stopped it, its automatic snifter turned it back into the cistern and the engine was not disturbed in the least. On starting the engine there never was anything beyond slight snappings, due to the condensing of steam in the cylinders insufficiently heated.

During the trial it required extreme and sudden changes in the rate (40 or 50 revolutions, for instance) to cause water to be carried over, and then in a very small quantity, which disappeared instantaneously. This saturation occurred mostly when the rate of steaming was decreased. In this respect the boilers of the Voltigeur possess remarkable qualities.

Purifying the feed-water.—The purifying of the feed-water is done perfectly; the use of lime-water in the course of experiments gave

ample proofs of this; and upon examination it was found that neither the tubes nor the feed-collectors presented any noticeable deposits. But the floors of the plane portions of the leading passages of the steam purifier had a layer of from 0.191 to 0.218 inch in thickness of adhesive black matter, being a mixture of calcareous salts and iron soaps.

In the ejector were found a large quantity of deposits of similar composition. One portion adhered to the partitions, and formed a funnel whose apex pointed down, reached a little below the orifice of the exterior extension of the snifting pipe. The balance of the deposits were in the form of concretions somewhat voluminous and compact, which filled the bottom of the ejector nearly up to the orifice of the blowing-out pipe.

Security.—An undeniable and very great advantage. The most serious accident that can befall the boilers of the Voltigeur is the bursting of a tube; this, however, is improbable, owing to the fusible plugs, which give timely warning of danger.

Quick pressure.—An extremely great advantage, and which, in the case of the Voltigeur, is demonstrated by the gain of nearly one hour over the time necessary to get an engine ready to work.

Relative lightness.—The weight of the boilers of the Voltigeur, excluding pipes, is 53.2 tons. Of the Chasseur, a similar vessel, 71.8 tons. The maximum production of steam per hour is: Voltigeur 8077 kilos ordinary firing, 9574 kilos forced firing; Chasseur 6593 kilos ordinary firing, 9571 kilos forced firing.

The tubes were perfectly clean in the interior; on the exterior appeared no signs of warping, but those tubes which were in direct contact with the flames were covered with a vitreous crisp coating easily removed, from 0.157 in. to 0.197 in. in thickness, apparently produced by drops of melted slags carried forward by the gases of combustion. It was specially when the fires were urged and with a high speed that these crusts were formed.

Sham repairs were made; they consisted in cutting the third tube of the front row of the second element of one of the boilers. The operation was performed in the manner already described, presented no difficulty, and took only about ten hours' time.

CONCLUSIONS.

The boilers are solidly built and well finished. Their peculiar apparatus for steam and feed-water purifying, as well as their self-

acting regulators of the state of the steam, are perfectly combined. All the attachments worked in a very satisfactory manner during the whole trial. While noting these advantages, the board does not pretend to cover the whole case of the boilers of the Voltigeur, but thinks that their working during ordinary steaming is a natural sequel to, and a necessary completion of, the trials. Many questions can be solved in that manner only. Attention must be drawn principally to the durability of the different attachments, to their possible breaking while in service, to their preservation when not in use, to the interior and exterior cleanings, to the working of the ejectors, to the different self-acting apparatus, and to the working and effects of protracted steaming with sea-water. The board cannot therefore deliver an absolute opinion upon the evaporative apparatus of the Voltigeur, but states emphatically that, in regard to security, lightness, rapidity of raising steam, facility of suddenly modifying the speed without risk of water being carried over, it presents great advantages, sufficient to counterbalance its drawbacks in the utilization of fuel, its complicated attachments, and the more arduous duty it involves.

Finally, the Board concludes by stating that the experiments made justify a careful examination of this style of boilers under the ordinary conditions of steaming, and that important advantages to the navy may result from the experiments made on board the Voltigeur.

NAVAL INSTITUTE, ANNAPOLIS, MD.

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RESCUE OF THE TRINITY'S CREW FROM HEARD'S ISLAND.

By ENSIGN W. I. CHAMBERS, U. S. N.

While at anchor off Montevideo, Uruguay, November 10, 1881, the U. S. S. Marion, Commander Silas W. Terry, U. S. N., commanding, received telegraphic orders to prepare at once for sea. Amid the excitement of hurried preparations, written orders were received from the Admiral, then at Buenos Ayres with his flagship, the substance of which was to proceed to Heard's Island in search of the crew of the American barque Trinity, a whaler which had not been heard from in eighteen months. In order to show that "orders" are not always infallible, and as well to note a curious coincidence in the position of two widely separated islands, situated in the same latitude south, it may be interesting to mention that a simple substitution of the word west for east, in naming the longitude, falsely indicated the Marion's destination to be one of those small nameless islands near the west coast of Tierra del Fuego in the South Pacific. It was found, however, on inspecting a private chart, that a small group of islands, named McDonald or Heard's Islands, existed in the South Indian ocean, in the same relative position *east* longitude, which, upon inquiry by telegraph, proved to be the intended destination.

The want of certain supplies and charts necessitated touching at Cape Town, South Africa, where the Marion arrived after a passage of twenty-eight days; and, on the arrival of a steamer from England with charts, which had been telegraphed for from Montevideo, she sailed for Heard's Island, December 24th, accomplishing the passage of about 3000 miles, under sail, in eighteen days.

On the morning of January 12, 1882, the small barren group of rocks called McDonald Islands were passed, it being customary for navigators bound to Heard's Island to pick up this group first, on account of the bad weather and lowering clouds which conceal the island of our destination almost every day in the year. The cloud-capped and snow-covered shores of Heard's Island were dimly visible at 4 P. M., and our course was shaped for the southeastern extremity, upon rounding which an unexpected line of angry-looking breakers was seen ahead, extending about four miles seaward. Sail was quickly shortened, and as the ship's head was turned away from the land, a party of men were discovered faintly visible under the cliffs, waving a flag from the top of a low hut. It was just then, too, that the clouds parted and permitted a momentary glimpse of the majestic, hoary head of Mount Emperor William, after which a snow squall shut out the island entirely from view.

The ship then steamed cautiously around the end of a long low spit of land, the limits of which were well marked by the breakers before mentioned, and which forms an open bay in which she anchored at 9 P. M., rolling deeply to the heavy ground swell during the entire night.

It was then too late to attempt a landing through the surf, and about 10 P. M. a bonfire was discovered burning on shore, which was kept ablaze, as afterwards determined, by the application of forty barrels of sea elephant blubber. This bonfire rather assured us that our search had not been in vain, as anticipated, and accordingly when a boat was sent on shore next morning we were not surprised to learn that the Trinity's crew was drawn up in a group on the beach, almost speechless with joy at the prospect of rescue. Then occurred the transfer of the shipwrecked party from the island to the ship—a tedious task which was executed without accident, save that one of the boats had a hole stove into her bilge by contact with rocks on the beach.

The story of the Trinity, as related by her officers, is briefly as follows:

The American barque Trinity, 516 tons displacement, owned by Lawrence Bros., of New London, sailed from that port June 1, 1880, with a crew of sixteen men, including officers, and on June 23d arrived at the Cape de Verde Islands, where an addition of nineteen Portuguese negroes was made to the crew. On the 26th the Trinity bore away for the South Indian ocean, intent on obtaining at Heard's Island

a cargo of sea-elephant oil, a substitute for whale oil, which brings three or four cents less per gallon in the market. The vessel arrived at the Kerguelen Islands, better known to whalers as Desolation Land, September 4, 1880, where the last letters were deposited in a rude box or postoffice used by whalers and sealers; and after transferring the light spars, spare sails and some provisions to suitable shelter on shore, she sailed, September 28th, for Heard's Island, about 270 miles to the southward, where she arrived October 2d, and anchored in Corinthian bay. At that place four of the crew were landed with four months' provisions, after which the ship was taken to Spit bay, fifteen miles more to the southward, October 12th.

It was intended to keep the ship anchored near the best beach for landing until the empty oil casks and necessary provisions were rafted to the shore, then moor her about two miles further up at a safer anchorage. After which, leaving a few shipkeepers on board, the crew would have debarked to live in the wooden houses on shore, which had been brought there for that purpose on former voyages, hunt and kill the sea-elephants and try out oil enough to fill the casks that had been landed. Then, reloading and reëmbarking, they would have returned for the party left at Corinthian bay, thence to Desolation Land for the stores and to the Cape de Verdes to leave the Portuguese negroes, and thence, finally, home to New London.

Had this scheme been successful, instead of having been overcome by disaster, we would probably have never known anything of these secret and perilous enterprises for elephant oil and gain. However, while engaged in sending the casks on shore, a northerly gale sprang up, and the doomed ship, with two anchors down, seventy-five fathoms of chain on one and ninety fathoms on the other, was dragged about the bay at the caprice of the wind, which came in violent gusts, sometimes on one side of the mountain and sometimes on the other. Having been unable, at a favorable time, to lift the anchors, which "had fouled something on the bottom," the ship was at length driven towards a part of the beach from which a dangerous shoal projects, and, to prevent grounding at that place, the jib, topsails and foresail were hastily set as the cables were slipped, and, paying off before the wind, she skirted the edge of the dangerous shoal and was driven upon a steep beach, with the flying jibboom within twenty feet of the land, about 9 A. M., October 17, 1880.

The ship was fortunately thrown up so well that an expert swimmer was enabled to take a line on shore, by means of which one of the

boats was afterwards dragged back and forth, and the safe landing of all hands, together with some clothing and about three months' provisions, was accomplished by dark that night. Many articles capable of floating were thrown overboard to be drifted to the beach through the breakers.

Wet, cold and exhausted they slept through the night, expecting to land the boats, tools and remaining provisions next day; but while they slept the gale hauled to the westward, and when they awoke next morning the ship was nowhere to be seen, having been driven off the beach, together with many articles which had been left lying there, and it is presumed that she foundered in deep water.

They were then forced to live on this exposed spit of land in three light frame huts, the officers taking possession of one, the white sailors occupying another and the Portuguese the third, and for a while they fared very well. Every day, when the weather would permit, hunting parties started out to patrol the beaches for sea-elephants in order to get something to eat, and especially the wherewithal to make a fire, and they thus managed by incessant hunting to get enough to eat. At first the elephants were often killed for the hearts, flippers and tongues only, before they could get accustomed to the flesh, which is said to resemble in taste that of the porpoise.

When the provisions began to grow scarce and the ration of bread was reduced to a tablespoonful of crumbs per day, they suffered much, but one of the worst trials came when the tobacco gave out, June 14, 1881; and when the last of the ship's provisions, which had been scrupulously hoarded, was finally consumed, September 12, 1881, they were obliged to depend entirely on the resources of the island.

Elephant meat, sea-fowl, and particularly penguins, together with a species of wild cabbage known as the Kerguelen cabbage, became in turn, according to season, their means of subsistence. The latter probably had a great deal to do with keeping the men in a healthy state, though they often had to dig through three feet of snow to obtain this valuable wild vegetable, which, after being boiled in sea-water by way of seasoning, was eaten, as expressively stated, for "stuffing" only.

It speaks well for penguin eggs as a very nutritious article of diet, that some of the officers and men gained from fifteen to twenty pounds in weight during the period when eggs were plentiful. The penguins, though easily caught at first, soon grew so wild and scarce

that it became very difficult and tiresome to catch them, as they propelled themselves over the ice and snow with a sliding, jumping motion, and there were days that, despite desperate hunting, only one or two penguins represented the entire catch of the various parties. It is easy to imagine how despairingly hungry the poor fellows must have felt even after partaking of the thirtieth portion of a penguin, the allowance for each.

It is not surprising that among the men there was occasional quarrelling. One stabbing affray occurred, but it was fortunately unattended with serious results. Sometimes as many as ten men were off duty at one time from weakness or sickness, produced generally by long enforced abstinence from food. There were also notorious shirks, who, under plea of sickness, hung around the huts all day, especially when the weather was unusually bad. Had not discipline been maintained, more than half of the men would have perished through their own recklessness, as some of them with that short-sightedness which comes from suffering and a weak will, were inclined when meat was more plentiful than usual, to surfeit themselves and not provide for long days ahead. But Captain Williams, who had before this been wrecked for a short time on this same island, understood the requirements of the situation, and to his credit maintained his authority throughout.

Clothing became worn out and scarce, and all sorts of ingenious devices were resorted to to make it last; for instance, tattered shirts and trowsers were backed by heavy canvas, and boots were shod with pieces of broken saws, but that of the poor Portuguese was so scanty that some of them were obliged to go stockingless and even barefooted at times.

It was thought that the month of January would bring more moderate and warmer weather, but instead, heavy gales with snow squalls were of daily occurrence, though the season was midsummer. In fact there were but three or four pleasant days during the three summer months. The huts were made as warm as possible by being covered with tussock. Hunting was kept up unceasingly, but days would pass without a sign of the animals which, even when sighted on the beach, were not easily secured, as it required the cover of darkness to surprise them, and the only weapons possessed by the hunters were lances.

During February, 1881, the bad weather continued with gales of wind and snow squalls nearly every day. During March the food

supply ran alarmingly short, but on the 24th of that month, when the situation was desperate, one of the parties succeeded in killing three sea-elephants, the flesh of which "kept the wolf from the door" for several days. Whenever a capture was made the hunters pulled the meat and blubber through the snow on rudely constructed sleds to the huts. During winter the snow lay three or four feet deep down to the water's edge. During April and May penguins frequented the island in large numbers. June, July and August were cold, dreary, cheerless months, and some days, with all hands hunting for food, the men would return weary and jaded without having secured anything to eat.

October 17, 1881, the first anniversary of the wreck, was a gloomy day, there being a strong gale from NNW. with snow and rain, during which the barometer fell to 28.45. There was not a mouthful to eat, and the men were in very low spirits indeed. Twelve months on the island and no sail had been descried! Worse still, on the previous day one of the men who had become demented by the hardships endured, had reported two sails in sight about two miles up the beach, to reach which all hands had started through the blinding snow then falling, only to find that the sails reported were two icebergs drifting past the island. Most of the poor sailors were by this time a walking mass of rags and many of their shoes were worn out, in consequence of the rough usage which their searches for food entailed.

They were enabled to exist, however, on the desolate island for fifteen months with the loss of but two men. George Watson, carpenter, and Bernard Kelley, seaman, who had been out during a storm on January 30, 1881, in search of penguins, were unable, through exhaustion, to return to the huts, and their frozen bodies were found next day, near one of the glaciers, with smiling upturned faces, cold in death. The bodies could not be removed until February 2d, when they were transferred to the beach, placed in one box and buried.

The four men left at Corinthian Bay fared better than their shipmates, but after remaining fourteen months without knowledge of the ship, became uneasy, and as land communication between the two harbors was impossible because of the bold shore and rugged glaciers which reach to the water's edge on all sides, they built a small scow 7½ feet long by 3½ feet wide, using the tools that had been left with them and some of the boards of which their house was made. Two of them, Henry Story, boatsteerer, and James Gill, seaman, started down to Spit Bay in this rude box, and, although the weather had

been unusually fine for several days, these brave fellows were twenty hours paddling their frail craft only fifteen miles.

Story took with him the tools necessary to build a better boat from the timber in the houses at Spit Bay, and in this way opened a safer means of communication between the two places. In the other boat, built like a dory, he visited Red Island, a detached rock, situated about five miles from Corinthian Bay, and there discovered an old whale-boat which needed a few repairs to make it serviceable, and it was intended to repair and utilize this boat later on for the purpose of visiting different parts of the island in search of food. However, bad weather postponed the execution of this design, until January 12, 1882, when the Marion arrived and gladdened their hearts with the sight of the "Stars and Stripes" which was hoisted in answer to their signal of distress.

About 4 P. M., January 13th, the Marion, under steam, started for Corinthian Bay against a gale of wind which so impeded her progress that it was too late when she arrived there to take the three remaining men on board that night. By 8 A. M. the next day all were safely on board, and forgetting past hardships in present joy, were taking a glad farewell of their late hoary-headed and relentless jailer, who, wrapped in a mantle of snow squalls, was soon hid from view.

The Marion then proceeded to the Kerguelen Islands, where, after anchoring for one night in Greenland Harbor, she was blown off shore by a northerly gale, thus preventing a visit to Betsy Cove where the Trinity's stores were stowed; and without further delay the course was shaped for Cape Town, where she arrived February 20, 1882, and where the State Department became responsible for the further care of the unfortunate whalers through the person of the U. S. Consul at that place.

Her arrival there was timely, inasmuch as she was able to render much needed assistance to the large iron English ship Poonah, which had recently been stranded on the Blauberg shore of Table Bay, and which was in constant danger of going to pieces should a northwest wind spring up.

Heard's Island—Retrospective Description.

Heard's Island, situated in latitude 53° 20′ south, and longitude 73° 10′ east of Greenwich, is about thirty miles in length and fifteen miles in width, extending in a direction about NNW. and SSE.

It was first discovered by an American captain named Heard during a voyage to the East Indies in 1853, who stated that he believed it to be a floating island, as he had sailed over its position repeatedly on former voyages. The floating island theory is destroyed by the fact that it contains an active volcano, and the inaccuracy of Captain Heard's navigation indisputably proven by various landmarks about the island which give evidence of former glacial action dating back certainly beyond the period of that worthy navigator's birth.

It is related that, at a later date, Captain Darwin Rogers in the old American whaling ship Corinthian was one day trying out elephant oil, in the bay named after that ship, when another ship hove in sight with the English Jack flying, her captain intent on taking possession of the island in the name of Queen Victoria. A sight of the "Stars and Stripes" thwarted this ambition, and a glance at the Portuguese negroes, dirty with the work of trying out, caused the jealous and disappointed Englishman facetiously to inquire whether they were specimens of free-born American citizens or natives of the island.

Rogers' Head at the entrance to Corinthian Bay is a remarkable headland, resembling at once a sphynx and a fortification. The marks on this natural parapet form such a perfect imitation of masonry that were it not for a knowledge to the contrary, one would imagine the harbor to be fortified; and the delusion is greatly enhanced by a very conspicuous line of red clay which apparently marks a cemented junction of the masonry with the slope of the hill upon which it rests.

This natural fort evidently once contained a powerful magazine of nature's combustibles, as may be inferred from the extinct crater which lies within its enclosure. On the left side of the entrance to the bay, which is about a mile wide, rests a majestic glacier, whose hard rough face, rising perpendicularly from the water about eighty feet, frowns coldly upon the stolid sphynx opposite; her head, rising about six hundred feet, seeming to brood in sullen silence over the memory of a rudeness to which she had been subjected by a former glacier, which had savagely brushed against her, scorning the battery at her back, and which had cut and scarred her face so much that many parallel curved lines or scars are yet left to remind her and posterity how the irresistible monster broke the ties that bound him to the narrow limits of Heard's Island and floated away to warmer climes.

At the southern extremity of the island a low narrow spit of land extends out to seaward about four miles. As the currents about the island almost invariably trend on either side along the shore towards

this spit, it is easy to conceive that it has been formed and constantly grows at the junction of these currents by deposits of lava and other *detritus* brought down from different parts of the island. Its shallow extremity is changeable in position according to the duration and violence of certain winds, and at times it has been noticed to extend in a direction at right angles to that of the main arm.

During the fifteen months of their confinement on the island the shipwrecked people seldom saw the summit of Mount Emperor William, which is estimated to be about 6000 feet high, but on November 27, 1881, the weather was clear enough to see what appeared to be smoke issuing from the mountain top in three columns. Again, on July 2d and 4th of 1881, three columns of smoke and one of fire were plainly visible. Frequent puffs of hot air were felt when the wind came from the direction of the mountain, and pools of water, occasionally found on the glaciers, were strongly impregnated with sulphur. It is probable that the volcanic nature of the island has something to do with the rapid change in the magnetic variation of the locality, which was found to differ by about 7° from that determined by H. M. S. Challenger during her memorable cruise.

However interesting the island may be to the student of natural history, it is not surprising that under the trying circumstances of their situation the Trinity's unfortunate men were unable to appreciate its interesting features.

In conclusion it may be well to add that from the appearances of the cloud formations observed to the southward of Heard's Island, and from observations on the flight of birds, it is believed that another uncharted island lies in that direction, from sixty to one hundred miles distant. True it is that the seals, many sea-elephants and penguins have left Heard's Island to rear their young elsewhere, and it is said that a certain sealing captain has discovered an island in this vicinity, the position of which, in the interest of the trade, remains a secret, by which he is able to realize large and easily obtained cargoes of seal skin.

PROFESSIONAL NOTES.

COLLISIONS AT SEA.

An article by Don Jose de Carranja, Spanish Navy, translated by Ensign Chas. C. Rogers, U. S. N., of the Office of Naval Intelligence, treats at length of recent improvements in nautical science by which the risk of collisions might be lessened. That naval discipline and the present rules of the road are insufficient was conclusively proved by the collisions resulting in the loss of the Vanguard and the Grosser Kurfurst. Attention is called to the necessity of using mechanical means for transmitting orders, avoiding risk of their being misunderstood; of utilizing steam or hydraulic power for steering, and particularly to the utility of turning trials of ships under all possible circumstances of wind, weather and speed, that the officers may become fully conversant with the qualities of their vessels. The latter part of the article is devoted to a consideration of different proposed improvements of the side lights, by which not only the position, but also the course steered, may be indicated with certainty at night, and this merits particular attention. Señor de Carranza says :

"In 1878, Messrs. Francis & Co., of London, inventors of the *Electric Ship Steering Indicating Lamp*, proposed an additional system of side lights to the present one ; from their descriptions we extract the following :

In the *Addenda* presented to the Woolwich Board, during the investigation of the loss of the *Princess Alice*, is expressed the following idea, which we deem worthy of adoption : 'We can never sufficiently impress upon the Board of Trade and Lords of the Admiralty why they should take into consideration the proposition of Captain Fitzgerald that ships carry two lights on each side ; then by the opening and closing of the lights would be indicated the side towards which the ships steer in their approach.'

This idea, included in the Francis plan, consists in placing vertically and near the usual side lights other lights with screens of red and green glass. Between the helm and these additional lights copper wires and a small battery are placed, disposed in such a way that when the helm is amidships bright white lights are shown ; but on putting it to port, for example, an alteration in the direction of the electric current raises the red screens or lenses, and both additional lights are seen red, showing that the helm has been put to port, turning the bow to starboard. In the same way the green lights are shown when the helm is put to starboard, turning the bow to port.

The lights and the helm, as already said, are connected by insulated copper wires, and the battery used supplies a constant current, and occupies, in fact, a

very small space between decks. The battery requires little attention, and the lights the same as either of the others.

The copper wires and the battery are insulated, and the lights, when in place, form the proper connections without any one being permanently stationed at them. Another peculiarity of the Francis Light is that the battery used is nearly always inactive, and at no time is a break through weakness to be feared. So little is the battery required that it is not absolutely necessary, since the sea itself can form a battery so well known, called the *salt water* battery, which is constant.

In addition to the side lights, the masthead and stern lights can be used. Then these last will indicate to ships approaching each other with great speed the direction in which the vessel ahead is steering.

In fact, without altering the plan, the lights required can be worked all at the same time, and by using simple telegraphic instruments there could not exist the possibility of a mistake, which is the fruitful cause of so many disasters.

Nor ought the loss of the English ironclad *Vanguard* to be forgotten, which, without doubt, with the lights we add, would have been able to show to the *Iron Duke* the direction in which she was steering, though in a dense fog. Messrs. Francis & Co. say that in consequence of the respectability of those who have testified to the importance of the light and the plan with which we are occupied, the British Parliament should institute a modification of the international system of side lights, requiring ships to carry a light working by electricity and indicating the course or helm. These gentlemen will exhibit to the London public, at the Eagle Telegraph Factory in Hatton Garden, their lamp or light working on models.

However, with the commendations and satisfactory results for which Messrs. Francis & Co. hoped, we are informed that this plan was submitted to the concurrence of maritime nations with the idea of altering the present system. But in spite of the fact that in all the many pamphlets and memorials that have been written, the existing plan is regarded as inadequate for the needs of the rapid steamers of this day, years pass and mishaps increase, and Great Britain owning the largest navy and mercantile marine in the world as well as the greatest wealth off the sea, will not take the initiative in meliorating the existing state of affairs, as humanity and interests certainly require.

In the Italian *Rivista Marittima* (Maritime Review) for July and August of 1882 is a description of the system of side lights proposed by Captain E. de Littrow, of the Imperial Austro-Hungarian Fleet, from which we extract the following:

'The principal cause of collisions at night lies in the defective system of lights, which provides when under way one green light on the starboard, and one red light on the port side.

With only one light, the change of a ship's course is not made sufficiently apparent to the eye, while with two lights of the same color on each side any turn, however small, to port or starboard to avoid collision can be seen at once. The distance between the side lights of the same color varies from 8 to 12 metres as the ship's size admits, and if made greater than this, so much the better will it be for the purpose intended.

The after light should not be visible except on the side through an arc of the horizon of 50° at most.

A ship with double lights seen end on, will show only *one* red and *one* green light, as the bow lights shut in the after ones. Whatever be the change of course, to port or starboard, it will be shown immediately by the appearance of the after light. When *b* sees the second red light he knows that *a* is changing his course to starboard, *a*'s red lights becoming gradually more distinct until seen with full brilliancy.

The after light should not be seen except from the *side* of the ship, and for this reason should be darkened on the forward side.

To avoid collisions, the relative movements of the ships must be known. This object is obtained with this plan of lighting.

Should either ship steer the wrong way, it will be detected at once, thus enabling the other vessel to avoid collision.

Take another example: *a* and *b* crossing so as to involve collision; *b* sees two green lights and understands that he should immediately port his helm and exhibit his two green lights to *a*. In this case no danger will be incurred, for *a* and *b* show two lights of the same color.

Experiments made on small ships with this modified system of lights have been attended with complete success, the results corresponding perfectly with the design. In the Austrian squadron on the coast of Dalmatia experiments are making on the larger ships. The greater cost of the light should not be considered, since it is used to more effectually avoid disasters and save human lives. Even in the present system of one colored light on each side, efforts are making to discover some berth or cabin light which can be exhibited to take the place of a second side light and show the tack or course on which a ship is steering. This want exists in every navy, and is sufficient to justify the adoption of a second side light.'

Mr. Littrow says nothing of the white stern light that is so necessary to a vessel stopping or sailing with less speed than the one following her on the same course.

We continue our subject with an extract on the system of lights designed by D. Jose Ricart Giralt, Professor at the Naval School, Barcelona, a description of which is published in the *Rivista Marittima* of this month:

'It is twenty years since all navies adopted the present regulation regarding side lights for the prevention of collisions, which establishes one green light to starboard, one red light to port, and one white light at the masthead of steamers, a system which without any doubt has proved of immense value, saving many lives and much material.

But for the very reason that the navy during these twenty years has undergone and is now passing through a radical change, with great increase in the number, dimensions and speed of steamers, we think that the present regulation is inadequate, and for that reason it is necessary to change it as soon as possible.

Now, on account of high speed the signal which a ship makes at night for the prevention of a collision should be a *speaking* one, in order to indicate with

certainty and at the moment the movement which the two ships ought to make without danger of doubt or loss of time.

The plan of Captain Littrow (already mentioned) printed in the *Rivista Marittima* of last July and August is a step in favor of our idea of a *speaking* signal; but, in my judgment, is incomplete, because like all modern systems it leaves the stern unlighted, as if there were no ships that move with greater speed than others. Besides, in the system mentioned, the two stern lights are given a range covering an arc of the horizon comprised between two perpendiculars to the keel, which causes the serious objection that a ship must describe a large arc before seeing the two green or red lights on the same side; finally, I do not think it advantageous for the two side lights to be of the same color, because in very large ships they would look, at a distance, like the lights of two different ships.

If the system be adopted, in my opinion the three following conditions should be fulfilled:

1. That the ship's lights be visible over the whole horizon.

2. That the lights of a ship, seen from any point, indicate the direction in which she steers.

3. That while the bow is passing through a small arc, the evolution that the ship is making be shown by the varying aspect of the lights visible.

In my opinion the plan of Captain Littrow is very far from fulfilling the conditions enunciated, and, for this reason, I am induced to present the following plan:

Every sailing vessel shall, when under way, carry the following lights:

On the starboard bow, a green light, so constructed as to show a uniform and unbroken light over an arc of the horizon of 115°—say ten (10) points of the compass, and so fixed as to throw the light from right ahead to 25°—say two points—abaft the beam on the starboard side. On the port bow, a red light, so constructed and fixed that it will fulfil the same conditions on the port side that the green light does on the starboard.

In the wing or on the quarters, on the starboard and port sides respectively, a white light, so constructed as to show a uniform and unbroken light over an arc of the horizon of 115°—say ten (10) points of the compass—and so fixed as to throw the light from right astern to 25°—say two points—forward of the beam on the starboard and port sides respectively.

Steamers, besides the lights required for sailing ships, should carry a white light at the foremost head, as at present.

Let us see if this system satisfies all the conditions that may arise:

1st Case. Two vessels meeting end on or nearly end on, so as to involve risk of collision, both ships should steer to port (*i. e.* the helms of both should be put to starboard,) so that each may pass on the starboard side of the other.'

(This is contrary to present regulations and its necessity is not shown.)

'2d Case. A ship which is being overtaken by another shall keep her course; and the one astern should alter her course to pass to leeward of the sailing ship which is ahead.

3d Case. Two ships crossing at right angles, so as to involve risk of collision. Both ships should steer to port until the ship whose red light is visible loses sight of the other's green light, and sees only the white light aft.'*

(This is contrary to present regulations and the necessity of a change is not shown.)

'4th Case. Two ships crossing at an oblique angle; if the angle be acute, both ships should steer to port until the one whose red light is visible loses sight of the other's green light, and the latter loses sight of the white light of the former.'

(Article 16, present Regulations, reads: "If two ships under steam are crossing so as to involve risk of collision, the ship which has the other on her own starboard side shall keep out of the way of the other." This manœuvre is contrary to the present rule, and the reason for changing it is not given.)

M. P. Prompt, in his pamphlet, says "That if the angle of crossing be acute, both ships should keep away; that is each should steer towards the side on which she does not see the other; the one that sees the other to starboard should slacken her speed, and give the way." We prefer these rules to those of Mr. Ricart).

If the angle formed by the courses be obtuse, both ships should steer to port until each sees the other's white light (aft).

(M. Prompt says: "When two ships are crossing at an obtuse angle, so as to involve risk of collision, both should steer to starboard." We prefer this rule to that of Mr. Ricart.)

'5th Case. Two ships steering on parallel courses, but in opposite directions. Each keeps on her course until she loses sight of the other's after white light.

6th Case. Two ships steering on parallel courses. Each keeps on her course, but if the one showing her red light disappears it will indicate that she has steered to port.'

I repeat that this system seems to me to fill the blank which exists in that of Captain Littrow, because, besides lighting the stern, the white lights are so fixed that they are seen at the instant the manœuvre begins; in other words, the system is a *talking* one, which is what mariners need. Our opinion about the rules that Mr. Ricart gives is expressed in parenthesis; but comparing his system with that of Captain Littrow, we think it has the advantage in placing a light at the ship's stern, which, among other plans, Mr. Francis suggested in 1878 and M. Prompt establishes in his pamphlet, though Mr. Ricart Giralt does not know it.

In comparing the descriptions of these schemes we meet with a discrepancy in both, since they say that the additional lights reveal immediately the least change of course in ships approaching. This is not the case.

Captain Littrow gives to the additional lights a range which covers an arc of only 50° of the horizon (on the sides), that is, until the ship has passed the danger of the bow or side, the additional light is useless.

Mr. Ricart, in his turn, says that the system should show with certainty

*Such a radical change is impracticable; besides there can be no necessity for it.—Trans.

and immediately the movement which the approaching ship is executing, without danger of doubt or loss of time. The additional lights of Mr. Ricart cover an arc of 114° of the horizon, or from right astern to two points forward of the beam, that is, that the ship in her approach passes through the risk of collision from the bow until two points off the beam.

The movements proposed by Mr. Ricart are analogous to those prescribed in our General Fleet Orders before the international rules were adopted. They conflict with those established by the latter system, and without showing the advantages in the change we think their adoption should be continued in all navies from this date.

The pamphlet entitled *Tactiques des abordages en mer et moyens de les prevenir* (Tactics of Collisions at Sea and Rules for Preventing them), published by Lieutenant M. P. Prompt, of the French Navy, is very interesting. It suggests that the lights be extended to the quarters and stern. From the study of these plans and of others in which the open light is discussed we infer that the idea of Captain Fitzgerald in 1878 was the same as that which Captain Littrow proposes. It seems more complete for practice, having the light aft, as many sailors have suggested and Lieutenant M. P. Prompt recommends in his pamphlet.

The system of Messrs. Francis, though we have seen it work satisfactorily, seems liable to confusion; but if through conclusive experiments it should meet with confidence, we would be inclined to accept only that part in which the white light forward shall be used to show, with a green or red lens, the direction in which the ship steers to avoid collision.

We are inclined more to the white lights than to the colored, for inasmuch as white lights are used in the flash signals of Captain Colomb, R. N., the red and green lights for squadron signals have disappeared. And we think that the colored side light should not be used, since its intensity is one-fifth that of the natural or white light.

What risk is there if the additional lights are visible from right astern to the range of the side lights if the result be to reveal immediately when the ship steers to starboard or port? We know of none, and for that reason we would suggest that wing lights cover the range astern and on the sides, thus improving the systems of Messrs. Littrow and Ricart.

If the lights were all white, both those on the sides and at the masthead could be made to emit short flashes on steering to starboard and long ones when turning to port. These signals could be used especially with ships close aboard and crossing each other's track. Sailing ships would carry, of course, only the side lights.

This subject merits greater consideration and study, for international interests require the solution of a system that will lessen the repeated collisions due to the daily increase in the number and speed of steamers.

The better English steamers from Liverpool to New York and Australia maintain a regular speed of fifteen or sixteen knots per hour, and when one of these vessels sights a colored light at night its distance in clear weather would be—say—two miles, a distance which they would pass over in four minutes, and during that time, if the courses cross each other, they should steer so as to avoid a terrible collision."

	10. Veston. 5 lamps.	11. Brush. 16 lamps.	12. Brush. 40 lamps.	13. Brush. 38 lamps.
Measurements of Power.				
1. Revolutions of generator per minute	1003	770	700	705
2. Horse power applied to generator	12.83	13.21	29.55	32.91
Electrical Measurements.				
3. Resistance of generator in ohms	1.88	10.55	22.38	22.38
4. Resistance of mains (without lamps)	1.50	2.56	2.60	7.90
6. Current in amperes	23.0	10.0	9.5	9.5
7. Fall of potential at each lamp, in volts	32.0	44.3	44.3	44.3
Electrical Calculations.				
8. Energy appearing in generator and mains in H. F	2.40	1.77	3.03	3.67
9. Energy appearing in one lamp in H. P.	.99	.59	.56	.56
10. Energy appearing in all lamps in H. P.	9.86	9.47	21.58	20.51
11. Total electrical energy in H. P.	12.26	11.23	24.61	24.18
12. Mean electromotive force	398	840	2009	1971
Photometric Measurements.				
13. Diameter of carbons, in millimetres	9 & 10	11	11	11
14. Horizontal illuminating power in candles, each la	874	352	§599	§599
15. Maximum illuminating power in " "	1463	722	741	741
16. Mean spherical illuminating power in " "	807	361	371	371
17. Total mean spherical " in candles, all	8070	5776	14840	14099
Results.				
18. Gross efficiency. Percentage of electrical energy t applied	95	85	83	73
19. Net efficiency. Percentage of energy in arcs tc applied	77	72	73	62
20. Percentage of total electrical energy appearing in	80	84	87	85
21. Candles per H. P. applied	629	437	502	427
22. Candles per H. P. of electrical energy	659	514	603	583
23. Candles per H. P. of energy in arcs	818	609	690	687
24. Candles per ampere	35.1	36.1	39.1	39.1
Additional Calculations.				
25. Total resistance of circuit	17.30	84.00	211.47	207.47
26. Total external resistance (mains and lamps)	15.42	73.45	189.09	185.09
27. Ratio of external to total resistance	.89	.87	.89	.89

* Afterwards found to be a defective machine.

† Self exciting machine, with two armature coils, one in main c

‡ Tested under abnormal conditions.

§ Evidently an error, as is seen by a comparison with the figurethe 40 light. This is probably an inversion and is designed for 36 carcels or 342 candles, which agrees well wit

TESTS OF DYNAMO MACHINES AT PARIS EXHIBITION, 1881.

Among other causes preventing an exact comparison of dynamo machines is the fact that tests are conducted differently by various persons both as to method and instruments employed, and it becomes difficult to institute a correct comparison between results obtained in different trials. Of late greater uniformity has come to exist, and the data obtained agree more closely. The Paris Exhibition presented the best opportunity of comparing the different types of dynamo machines that had been offered up to that time, and a committee composed of well-known experts was appointed for the purpose of making exact tests. The accompanying table exhibits the results attained, and as the measurements were made by the same persons, and as nearly as practicable under the same conditions, they afford the best means yet published of deciding on the *relative* merits of the different machines. It is worthy of notice that the measurements of light are lower than those generally obtained, but if all are lower the *relative* merits are unaffected. The table is copied from the New York Electrician for February, but the French measurements of power and light are recalculated, and expressed in English horse power and candles to facilitate comparison with other measurements. One or two obvious errors have been corrected and attention called to others in which the amount of error is uncertain.

	1. Gramme 1 lamp	2. Jürgensen 1 lamp	3. Maxim 1 lamp	4. Siemens 1 lamp	5. Siemens 2 lamps	6. Bürgin 3 lamps	7. * Gramme 3 lamp	8. Gramme 5 lamps	9. Siemens 5 lamps	10. Weston 10 lamps	11. Brush 16 lamps	12. Brush 40 lamps	13. Brush 38 lamps
MEASUREMENTS OF POWER.	Hand lamp	Serrin lamp	Maxim lamp			Crompton							
1. Revolutions of generator per minute	475	800	1017	737	1330	1535	1645	1496	826	1003	770	700	705
2. Horse power applied to generator	15.41	21.38	4.01	4.38	5.24	5.25	8.00	7.89	4.98	12.83	13.21	29.55	32.91
ELECTRICAL MEASUREMENT.													
3. Resistance of generator in ohms	0.33	0.45	0.70	0.66	1.68	2.80	10.52	4.57	7.05	1.88	10.55	22.38	22.38
4. Resistance of mains (without lamps)	0.10	0.82	0.25	0.12	0.13	1.50	1.25	0.62	4.50	1.50	2.56	2.60	7.90
6. Current in amperes	109.2	90.0	33.0	35.0	26.2	18.5	19.0	15.3	10.0	23.0	10.0	9.5	9.5
7. Fall of potential at each lamp, in volts	53.0	58.0	53.0	53.0	44.5	41.0	53.0	49.8	47.4	32.0	44.3	44.3	44.3
ELECTRICAL CALCULATIONS.													
8. Energy appearing in generator and mains in H. P.	6.87	13.80	1.39	1.27	1.67	1.97	0.86	1.63	1.55	2.40	1.77	3.03	3.67
9. Energy appearing in one lamp in H. P.	7.76	6.87	2.28	2.49	1.57	1.02	1.35	1.03	.63	.99	.59	.56	.56
10. Energy appearing in all lamps in H. P.	7.76	6.87	2.28	2.49	3.14	3.04	4.05	5.13	3.16	9.86	9.47	21.58	20.51
11. Total electrical energy in H. P.	14.64	20.67	3.67	3.76	4.81	5.01	4.91	6.76	4.70	12.26	11.23	24.61	24.18
12. Mean electromotive force	102	172	84	80	136	203	193	328	353	398	840	2009	1971
PHOTOMETRIC MEASUREMENTS.													
13. Diameter of carbons, in millimetres	25	23	12	18	14	13	14	12	10	9 & 10	11	11	11
14. Horizontal illuminating power in candles, each lamp	9044	5707	2337	1995	1349	475	1473	1064	637	874	352	§599	§599
15. Maximum illuminating power in " " "	18620		4418	7048	5102	2156	3392	1748	684	1463	722	741	741
16. Mean spherical illuminating power in " "	9177	6536	2271	2907	1947	779	1586	969	494	807	361	371	371
17. Total mean spherical " in candles, all lamps	9177	6536	2271	2907	3895	2337	4758	4845	2470	8070	5776	14840	14099
RESULTS.													
18. Gross efficiency. Percentage of electrical energy to power applied	92	97	91	86	92	95	62	86	94	95	85	83	73
19. Net efficiency. Percentage of energy in arcs to power applied	43	32	57	57	60	58	51	65	63	77	72	73	62
20. Percentage of total electrical energy appearing in arcs.	53	33	62	66	65	61	83	76	67	80	84	87	85
21. Candles per H. P. applied	576	306	565	663	743	445	595	614	496	629	437	502	427
22. Candles per H. P. of electrical energy.	627	316	618	773	811	466	967	717	526	659	514	603	583
23. Candles per H. P. of energy in arcs.	1240	590	1097	1169	1245	769	1171	945	783	818	609	690	687
24. Candles per ampere	84.1	72.6	68.8	83.1	74.3	42.1	83.5	63.3	49.4	35.1	36.1	39.1	39.1
ADDITIONAL CALCULATIONS.													
25. Total resistance of circuit	.93	1.91	2.55	2.29	5.19	10.97	10.16	21.44	35.30	17.30	84.00	211.47	207.47
26. Total external resistance (mains and lamps).	.60	1.40	1.85	1.63	3.51	8.17	9.64	16.87	28.25	15.42	73.45	189.09	185.09
27. Ratio of external to total resistance	.65	.70	.73	.71	.68	.74	†.95	.79	.80	.89	.87	.89	.89

* Afterward found to be a defective machine.

† Self-exciting machine, with a [illegible] current and the [illegible] current of the field coils. The latter is not included in the internal resistance of the generator.

‡ Tested under abnormal conditions.

§ Evidently an error, as is seen by a comparison with the figures obtained with the 16-light machine in line 16. In line 14 the tables give 37 candels for the 16 light, and 73 candels for the 40 light. This is probably an inversion and [illegible] which agrees [illegible] with the ratio in line 16.

TESTS OF DYNAMO MACHINES AT PARIS EXHIBITION, 1881.

Among other causes preventing an exact comparison of dynamo machines is the fact that tests are conducted differently by various persons both as to method and instruments employed, and it becomes difficult to institute a correct comparison between results obtained in different trials. Of late greater uniformity has come to exist, and the data obtained agree more closely. The Paris Exhibition presented the best opportunity of comparing the different types of dynamo machines that had been offered up to that time, and a committee composed of well-known experts was appointed for the purpose of making exact tests. The accompanying table exhibits the results attained, and as the measurements were made by the same persons, and as nearly as practicable under the same conditions, they afford the best means yet published of deciding on the *relative* merits of the different machines. It is worthy of notice that the measurements of light are lower than those generally obtained, but if all are lower the *relative* merits are unaffected. The table is copied from the New York Electrician for February, but the French measurements of power and light are recalculated, and expressed in English horse power and candles to facilitate comparison with other measurements. One or two obvious errors have been corrected and attention called to others in which the amount of error is uncertain.

BIBLIOGRAPHIC NOTICES.

ANNALEN DER HYDROGRAPHIE UND MARITIMEN METEOROLOGIE.

No. 12, 1882. The four voyages of the Dutch ship Willem Barents to Barents sea in 1878–1881. The thunderstorm of Aug. 9, 1881. Oceanographic observations in the South Atlantic Ocean from July to Sept. 1882. Oceanographic observations in the Gulf Stream from April to July, 1882. Entries in the meteorological journals of the German observatories for Aug. 1882. Comparison of the weather of North America and Central Europe for Sept. 1882. Cruise report of ships of the Imperial navy for 1882.

No. 1, 1883. The physical geography and meteorology of the Cape of Good Hope. Deep sea soundings of Siemens' steamer Faraday. The hurricane in the Indian Ocean in May, 1881. Rules for the handling of chronometers (from Proc. U. S. Naval Institute). Entries in the meteorological journals of the German observatories. Thursday Island. Comparison of the weather of North America and Central Europe for Oct. 1882. Brief hydrographic notices.

PROCEEDINGS AMERICAN PHILOSOPHICAL SOCIETY.

Vol. XX, No. 110. A Manual for the Use of Students in Egyptology. By Commo. Edward Y. McCauley, U. S. N.

No. 111. The inclination of the apparent to the true horizon and the errors rising thereof in transit, altitude and azimuth observations. The aurora of April 16–17, 1882. Photodynamic notes.

No. 112. Radiant heat an exception to the second law of thermodynamics. Photodynamic notes.

TRANSACTIONS AMERICAN SOCIETY OF CIVIL ENGINEERS.

October, 1882. Preservation of Timber.

The society has appointed a committee to investigate this important question, and the present number is devoted to the preliminary report of the committee and to the consideration of papers by several members upon the merits of certain special methods, and to discussion upon the same.

November. Rapid Methods in Topographical Surveying.

December. Discussion of Paper on Rapid Methods in Topographical Surveying. Weights and Measures. Care and Maintenance of Iron Bridges.

In discussing this last paper Theodore Cooper considers at length the subject of the corrosion of iron, and sets forth the conditions under which the corrosion goes on most rapidly, and the means by which it may be arrested.

A Peculiar Phase of Metallic Behavior.

In Sept. 1881, an invoice of so-called gilding metal, presumably an alloy of copper and zinc, was received at the Frankford Arsenal for the manufacture of cartridge cases. Owing to the uniform success of his output, the contractor who supplied this metal had come to be regarded as the maker of standard sheet cartridge copper. This particular delivery was subjected to the usual severe treatment, met every demand, underwent every proof in the customary satisfactory manner, but failed in the firing test, of course a fatal defect. The contractor was notified and saw convincing evidence of the failure, but he stated positively that this especial lot of metal had been treated in precisely the same manner as the accepted invoice immediately preceding it, and that he was unable to account for its shortcomings. Capt. O. E. Michaelis, Ord. Corps, U. S. A., describes all the tests applied and illustrates his descriptions with diagrams and plates. He concludes : "From my recent experience with this metal, I believe it, in a measure, confirms the theory of refreshment first expounded by a member of the society ; it appears to be in better condition now than at the time of its rejection seven months ago. No adequate reason can be assigned for the final failure of the metal, that so successfully passed through all the exhaustive tests established by extended experience and profound theory. It simply 'broke down' in an inexplicable, unexpected manner. Though but a straw, this failure leads my mind to harbor the heretical misgivings that preliminary static tests of materials furnish data useful only in the solution of questions in the calculus of probabilities. Nothing positive can be drawn from their consideration." Discussing this paper, Dr. Egleston said cartridge metal is not of constant composition, being sometimes of brass with a large per cent. of zinc, and sometimes copper with just zinc enough to make the copper draw with certainty. The latter passes under the name of gilding metal. Failures of punched and spun brass are quite common, and manufacturers allow for a certain percentage in their specifications. The sources of failure are numerous with these alloys. First, copper is a very delicate metal, and a very small percentage either of its own oxide or of other impurities will ruin it for commercial purposes. In the hundreds of samples of commercial copper which he had examined he had not found, until within two years, since the perfection of certain processes of refining, copper that could even be called commercially pure. It generally contains, besides oxygen, small amounts of lead, zinc, cobalt and nickel. This is true to a great extent of the coppers produced in the great Appalachian range, and to a less extent of those of Lake Superior, which have always been considered, until copper began to be produced from Arizona, as the best copper in the world. This copper may be spoiled in the refining or in the melting by which brass is to be made. It may be spoiled by oxidation in the melting ; by over-heating or under-heating in the annealing ; or by over-compression in the rolling. Over-compression or over-heating causes the metals to "flow," and they separate. He has sampled as many as 500,000 cartridges in a factory by firing, and found that many could only be fired once, a few would fail on the second firing, still fewer would fail at the third, and occasionally cartridges could be found in the same batch of metal which would fire 150 times. In every case the failure was due to the same cause, and after examining hundreds of them he became satisfied that this cause was either too great compression or too much heat ; this being true even in those samples which contained a minimum quantity of the volatile metal. He has separated from many of these metals volumes of gas which were five, sometimes ten, times the bulk of the metal, and hopes at some future time to analyze this gas. This phenomenon of the separation of gas always occurs in those metals which have been most compressed, and it would appear as if the brittleness was owing, in a great many cases, to the expansive force of the gas at high pressure, which is a force within the metal tending to help any force applied from without which would deteriorate it.

ENGINEER.

JANUARY 12, 1883. The Loss of the City of Brussels.

The first point worthy of notice is that the case of the ship, after she began to leak, was hopeless. But nevertheless, unaided by any assistance from the crew, she did not founder for about twenty minutes. It is clear then some obstacle prevented the water finding its way through the whole ship at once. The ship was however divided into seven water-tight compartments, and the reason assigned for her foundering was that the "Kirby Hall" struck her at the end of a bulkhead and so knocked two compartments into one. This, however, is to a great extent pure conjecture; and even if it is true, then the circumstance furnishes another argument in favor of so constructing bulkheads that two compartments cannot be knocked into one. But assuming the bulkhead was what it was—insufficient beyond a certain point—it is easy to see that had very moderate pumping power been brought into play, the ship could have been kept afloat. The utmost quantity of water to be dealt with was about 2000 tons lifted say, 20 feet in 20 minutes; this represents 448,000 foot pounds per minute or 135 horse power; or making large allowance for waste, an engine of 250 horse power, properly used, would have kept the water pumped out as fast as it came in. In most of the great passenger steamers recently built, immense pumping power has been provided; but the City of Brussels was thirteen years old and sufficient importance was not then attached to pumps. It is a noteworthy fact that bulkheads as usually fitted are absolutely worthless. In this statement the collision bulkheads are excepted, for they alone are invariably well made, well designed, and therefore efficient.

Copley's Compound Launch Engine. Nabholtz's Improved Frictional Rivetter.

This machine has put in, in one hour, 480 $\frac{3}{4}$-in. rivets into plain girders, the work being already drifted and prepared, so as to have no other impediments but to take the bolts out and turn the work.

JANUARY 19. The Prevention of Scale in Steam Boilers. The Principles of Modern Physics. A Criticism on Mr. J. B. Stallo's Concepts and Theories of Modern Physics. Crucible Cast Steel Rudder for S. S. La Plata.

The La Plata having nearly proven a loss by the breaking of her rudder during a storm in the North Sea, it was determined to try crucible cast steel. The rudder having been successfully cast was subjected to the following tests: The rudder was laid horizontally, with its ends resting on supports. The rudder blade was loaded with an evenly distributed weight equal to a total of 12,300 lbs., and balanced by a weight of 2240 lbs. at the end of a lever 12 feet long, securely fastened to the rudder-head $6\frac{1}{2}$ ins. diam. The effect of the lever itself was 3920 lbs., weighing as it did 784 lbs., with an effective length of 5 feet. The rudder-head therefore sustained a torsional strain of $(2240 \times 12) + (784 \times 5) = 30{,}800$ foot pounds. While under this torsional strain a 2000 lb. weight was dropped from a height of four feet, striking at centre of the area of blade, and in neither case was there any sign of a twisting movement in the rudder-head. The rudder was then lifted to a height of 9 feet and dropped on the hard floor of the foundry without the slightest fracture. Being suspended again and tested with hand hammers, it rung like a bell from end to end.

Steam Boiler Furnace Economy.

An editorial on the subject of smoke prevention and furnace economy.

JANUARY 26. The Electrical Transmission of Power, by Prof. Oliver J. Lodge. The Movement of the Water in a Tidal River, by Prof. W. C. Unwin. The Foundering of Steamships.

Commenting on the sinking of the Cimbria and the frightful loss of life attending it, following so quickly as it does on the loss of the City of Brussels, attention is called to the utter thoughtlessness or carelessness with which owners of iron ships are allowed to send them to sea. Some figures are given showing the utterly insufficient strength given to bulkheads, which usually consist of plates ½ inch in thickness or less, stiffened by a few angle irons quite incapable of sustaining a hydrostatic pressure of 6 lbs. or 7 lbs. per sq. in. A double bottom in addition to high pumping capacity is earnestly demanded as a needed reform.

Regulator for Dynamo-Electric Machines.

A machine, patented by Mr. Maxim, for which the inventor claims the combination, with a dynamo-electric machine, of brushes arranged to revolve about the commutator, a system of gears for shifting the brushes, a reciprocating lever or pawl arranged to impart movement to the gears in either direction, and an electro magnet controlling the position of the reciprocating pawl.

FEBRUARY 9. Causes of Glacier Motion. Read before the Royal Society, by W. R. Browne. The Polyphemus.

This vessel is nothing but a ram, unless she is also an utter failure. She is fitted with special appliances for discharging torpedoes under water from her bows and her sides; and up to the present nothing but disappointment has attended every effort to use these last. The torpedoes fired from the bow ports have at all events been got away from the ship; but as much cannot be said of those discharged from her broadside.

The Polyphemus has attained a speed of 17 knots per hour, and the moment the torpedo shows its nose outside of the hull, it is deflected by the apparent current alongside the ship, and it is therefore jammed in the tube. If it can be got clear of this, it is only with its screw blades broken and its tail twisted that the luckless torpedo gets off; and it is not curious that the short curve which it then describes is erratic in the extreme. To prevent this a steel plate is pushed out from the ship's side, and under the lee of this the torpedo is discharged; but the resistance of the water has bent the steel bar, leaving the torpedo sticking half in and half out of the ship. Up to the present the targets aimed at, at distances of but 200 and 300 yards, appear to be specially avoided by the torpedoes, the ship steaming at 8 knots an hour or less. It is now also officially announced that the boilers are to be removed, but it is not announced how they are to be taken out, as the turtle-shaped deck is covered all over with Whitworth steel tiles, and to get those off and replace them without racking the whole structure, will be no easy matter.

The Electric Light on H. M. S. Himalaya. The Transmission of Power by Electricity.

An exhibition of the transmission of power by the system of M. Deprez. The trial did not prove as effective as was hoped, although M. Deprez claims that he has already demonstrated from an electrician's point of view, the correctness of his system.

FEBRUARY 16. Battle Ships, by Mr. Nathaniel Barnaby, C. B.; read before the United Service Institution.

Mr. Barnaby looks forward to ships of about 2000 tons displacement, carrying two heavy guns of about 25 or 30 tons each, one firing ahead and the other astern; the vitals of the ship are to be protected as far as possible by being placed below water, and by the use of horizontal armor decks. He expects that side armor will almost entirely disappear, being confined to a thick steel-faced or steel wall, protecting heavy guns; and that consequently the onslaught will consist chiefly in what has been termed the secondary attack made by common shells on unarmored parts of the ship.

ENGINEERING.

JANUARY 5, 1883. The "Bausan."

A new vessel in the course of construction at the Elswick works for the Italian Government. Length over all, 296 ft. and 42 ft. beam; displacement, 3020 tons. The ship will have twin screws driven by two pairs of compound engines of 5500 total horse-power, imparting a velocity of about 17 knots per hour. She will carry 600 tons of coal, 200 of which will be supplementary and are not allowed for in the displacement given above. With a full supply of coal on board she will be able to steam 5000 miles at a reduced speed of 10 knots. The armament will consist of two 25-ton breech-loading guns of the Elswick pattern on the ribbon coil system, firing a projectile of 3 cwt. with a charge of 182 lbs. of powder, and considered capable of penetrating 19½ inches of compound armor, and six 6-inch breech-loaders firing 60-lb. projectiles. The two large guns will be placed, one at the bow and the other at the stern, mounted on pivoted frames, and capable of being trained so as to embrace an angle of 240° each. The ship will have three sets of torpedo-discharging apparatus, one at each side and one at the bow, and will also be furnished with a powerful ram. The total cost including arms and ammunition is to be but £160,000.

JANUARY 12. Clyde Shipbuilding and Marine Engineering in 1882.

A summary of the work done on the Clyde during the past year.

The Use of Concrete in Marine Construction.

JANUARY 19. The Nordenfeldt Machine Guns. A complete description of all the Nordenfeldt Volley Guns. Timmis & Hodgson's Reversible Life Boat.

Received the first prize at the Naval Exhibition, and consists of two similar tubular hulls or chambers connected by a horizontal platform. Along the top and bottom of each chamber is a strip which serves either as a keel or gunwale, according to which half of the boat is above water. The hull is made of steel provided with water-tight bulkheads. The deck is open, and for a ship's boat is made of network, so that it can be launched without davits and in any position, it being a matter of indifference which side comes uppermost in the sea.

Sinclair's Self-acting Stoker.

A description of mechanical firing by Sinclair's method. The contrivance has been applied to upwards of 200 furnaces, effecting in most cases it is claimed an important saving in fuel and an increase in the production of steam, with, at the same time, almost complete cessation of the evolution of smoke.

Modern Ordnance.

An examination of the various breech-loading systems which approach the requirements of a perfect gun.

JANUARY 26. King's Governor for Water Motors. Manufacture of Pig Iron in Sweden. Electric Lighting. The Report of Mr. C. W. Cook on the Probable Cost of Lighting by Incandescence on a Large Scale.

FEBRUARY 2. Steel.

Papers read before the Institute of Mechanical Engineers on the amount of carbon in steel and the molecular rigidity of tempered steel, by Prof. D. E. Hughes, F. R. S.

Drilling, Boring and Shaping Machines. Siemens-Martin Furnaces at the Graz Steel Works. Girdwood's Isometric Governor.

Its action is based upon the use of an appliance that offers a resistance to rotation and increases with the velocity. The appliance used in this case is a hollow drum partly filled with fluid and rotating on a horizontal axis. When the cylinder is put in motion, the liquid is carried up one side to a height that is determined by the speed, and, if the motion be uniform, it will remain at that point, and will offer a resistance to rotation which increases in proportion to its lateral displacement of its centre of gravity. Should the speed increase, the liquid will rise still higher and offer additional resistance. These varying resistances are balanced by a spring which responds to them by contracting and expanding, and in so doing gives the motion for operating the governing mechanism.

FEBRUARY 16. Non-Conducting Coverings for Boilers and Steam Pipes.

A lengthy and comprehensive series of experiments to determine the comparative efficiencies of the different non-conducting coverings that are now in the market.

An Automatic Primer for Pumps.

An exceedingly simple and ingenious method devised by Mr. Normand, for expelling the air which accumulates in the clearance space of pump barrels and in the valve chambers. To obviate the necessity of pet cocks, and to prevent the cessation of pumping, a small pipe about $\frac{3}{16}$ in. in internal diameter is introduced into the pump at the highest point at which the air can accumulate, while the other end opens into the tank from which the water is drawn. When the plunger descends, the air which may be in the barrel is compressed and escapes through the tube, bubbling up through the water. When the plunger ascends, the water passes through the tube and into the pump, and thus priming it without the attention of any one in charge.

JOURNAL OF THE FRANKLIN INSTITUTE.

JANUARY. The Chemistry of the Planté and Faure Accumulators. The Spectroscope and the Weather.

An exhibit by the Astronomer Royal of Scotland of some of the results obtained in predicting rain by the "rainband spectroscope." Some observations made are as follows:

Date.	Mean Temp.	Intensity Rainband.	Rainfall Observed.
Sept. 1, 1882.	57.1 F.	3	.044 inch.
2	59.2	2	.353
3	58.6	2	.015
4	54.4	0	
5	55.7	1	
6	55.2	0	
7	53.8	1	
8	59.4	0	
9	54.0	1	
10	57.0	1	
11	52.2	1	.40
12	48.6	0	
13	52.8	1	
14	49.5	3	.62
15	56.2	2	.57

The intensity of the rainband is of course estimated, and the accuracy with which this intensity can be estimated seems at present to limit the utility of the spectroscope as a meteorological instrument.

MARCH. Crank Pins of Marine Engines (J. H. Whitham, U. S. N.)

GIORNALE D'ARTIGLIERIA É GENIO.

NOVEMBER, 1882. Austrian siege gun of compressed bronze, model of 1880. The new trains made of nine centimetre plates. The Japanese breech-loading gun, model of 1880. The military telegraphic service in France.

JOURNAL OF THE MILITARY SERVICE INSTITUTION OF THE UNITED STATES.

No. XII. Field artillery in the United States before the civil war. Extracts from the history of Franco-German war. Mina and his three hundred. Notes on fundamental points in our military system.

INSTITUTION OF MECHANICAL ENGINEERS.

NOVEMBER, 1882. The Fromentin automatic boiler feeder. Experiments on flanging steel plates cold by hydraulic pressure. Experiments to ascertain the strength of cast iron beams for beam engines.

MITTHEILUNGEN A. D. GEBIETE D. SEEWESENS.

No. II. The type of the modern marine engine. Type of the modern battle ship. Organization, administration and material of the French navy. Russian marine ordnance. 100-ton gun of the Italian navy. Caspersen's pendulum chronograph. Ader's microphone sender. Notes on the French and Russian navies. The French and American expeditions for the observation of the transit of Venus.

REVISTA GENERAL DE MARINA.

DECEMBER, 1882. Notes on Service in the Philippines. On Naval Combats between 1860 and 1880. Tallerie Hydraulic Motor. The Dandolo. Lights of Safety.

A scheme of Capitan de Fragata Mansanos for avoiding collisions at sea involves the addition of two extra side lights which he calls "lights of safety." The ordinary running lights would be carried as usual, but placed well aft, while the safety lights would be placed on the forecastle or in the fore-rigging. Parallel screens are placed on either side of these lights at an angle of 45° with the keel, of such a length as to prevent their being seen except in an arc from nearly ahead to 10° forward of the beam. The lights would be of the same color as the running lights, red and green respectively. The plan is designed for steamers only, the presence of the masthead light avoiding all risk of the lights being taken for those of two vessels standing in the same direction. The safety lights being visible only broad off the bow would indicate within a few points the course steered by the vessel carrying them, while a change of course would be made evident by the appearance or eclipse of these lights, the ordinary side lights and masthead light continuing to show as before.

JANUARY, 1883. Notes on Naval Service in the Philippines. Tallerie's Hydraulic Motor (in use aboard the Aragon for working the helm). Naval Organization. Dimensions of Fundamental and Derived Units. Notes on the London Electrical Exhibition. Determination of Position at Sea by Circles of Equal Altitude. Notes on Combined Military and Naval Operations.

FEBRUARY. Notes on Naval Service in the Philippines. Fundamental and Derived Units. The London Electrical Exhibition. The Aneroid Barometer. Notes on Combined Military and Naval Operations.

Automatic Electric Lighting Apparatus for Beacons.

An automatic apparatus used on a beacon in the harbor of Cadiz. By means of a clock-work regulator and an electro-magnet, a light is produced for ten seconds at a time, with twenty second eclipses throughout the night, the light being caused by the inflammation of benzine vapor by the sparks of a Ruhmkorff coil. During the eclipses and during the day there is no loss of benzine, and the batteries are cut out of circuit by an insulator in the clock-work. It is said to have worked without the slightest interruption since May 16, 1881, requiring occasional attention only.

RIVISTA MARITTIMA.

NOVEMBER, 1882. Reflections on naval tactics. The naval appropriations. On the formation of cyclones. Naval warfare, the military ports of France (trans.) Thornycroft torpedo boats (trans.) Experiments at Meppen (trans.) Collisions at sea.

DECEMBER. Notes on naval tactics. The Italian naval appropriations. The mercantile marine and the auxiliary fleet in war. The naval review of 1882. The cruising torpedo ram. The physiology of cyclones.

JANUARY, 1883. Notes on naval tactics. Coast defense. The national marine strength. The Italian naval appropriations. Progress in the navy. On ironclads and the modern naval combat. Experiments with plates at Spezzia. The proportion of officers in the navy.

THE UNITED SERVICE.

MARCH, 1883. Relative Rank of the Officers of the Austrian, German, Italian, French, English and United States Navies, arranged on the basis of the Army Rank.

This article, translated from the "Mittheilungen a. d. Gebiete des Seewesens," by Prof. C. E. Munroe, is valuable for reference, giving, as it does, not only the exact relative rank of officers of foreign navies with those of our own, a point not always easy to determine, but also showing the relative rank of officers of different corps in each of the leading navies of Europe.

MÉMOIRES DE LA SOCIÉTÉ DES INGENIEURS CIVILS.

OCTOBER, 1882. Report on the International Congress of Hygiene and of the meeting of the French Association for the Advancement of Science. Description of the port of La Rochelle. The coal of Asia Minor. Utiliza-

tion of the subterranean heat. The coal production of Sweden. Distillation of sea water at Alexandria during the Egyptian War. Valves of phosphor-bronze. The attractive force of steel rendered permanent by compression. Bourdon's registering anemometers.

NOVEMBER, 1882. The coal industry in Austria. Shipbuilding on the Clyde.

Memoir on Thermodynamics.

This memoir embodies a new theory of gases, in which the laws of Gay Lussac and Mariotte, which fail for certain gases like carbon dioxide, and the hypothesis of a perfect gas, are abandoned. The theory is tested by comparison of the calculated data with the results of experiments, and it is applied to the interpretation of isothermal and adiabatic curves.

BOOKS RECEIVED.

Almanach für die K. K. Kriegsmarine. 1883.
American Geographical Society. No. 2, 1882.
American Society Civil Engineers. Oct., Nov., 1882.
American Institute of Mining Engineers. Nineteen Papers.
American Philosophical Society. Transactions, Nos. 110, 111, 112.
Conziderazioni sulla Tattica Navale.
Giornale d'Artiglieria é Genio. Nov., Dec., 1882, Unofficial; and Nos. 7, 11, 12, 13, 15, 16, 17—1882, Official.
Institute of Mechanical Engineers (England). Transactions, No. 4, 1882.
Journal de la Flotte. No. 53, 1882, to No. 9, 1883, inclusive.
Journal of the Franklin Institute. Feb., Mar., 1883.
Journal of the Military Service Institution of the United States. No. 12.
Journal of the Royal United Service Institution. No. 118.
Nautische Tafeln der K. K. Kriegsmarine.
Réunion des Officiers, Bulletin. No. 51, 1882, to No. 4, 1883, inclusive.
Report of Ch. Eng. Isherwood on Vidette Boats built by the Herreshoff Manufacturing Co. for the British Government.
Rivista Marittima. Jan., Feb., 1883.
Royal Artillery Institution. Proceedings, Vol. XII, with Précis and Translations.
School of Mines Quarterly. No. 2. Vol. IV.
Société des Ingénieurs Civils. Mémoires, Oct., Nov., 1882.
United Service. Mar., 1883.
U. S. A. Ordnance Notes. Nos. 233, 234, 235.

AMERICAN PHILOSOPHICAL SOCIETY,

PHILADELPHIA, PA.

EXTRACT FROM THE BY-LAWS.

CHAPTER XII.

Of the Magellanic Fund.

SECTION 1. John Hyacinth de Magellan, in London, having in the year 1786 offered to the Society, as a donation, the sum of two hundred guineas, to be by them vested in a secure and permanent fund, to the end that the interest arising therefrom should be annually disposed of in premiums, to be adjudged by them to the author of the best discovery, or most useful invention, relating to Navigation, Astronomy, or Natural Philosophy (mere natural history only excepted); and the Society having accepted of the above donation, they hereby publish the conditions prescribed by the donor and agreed to by the Society, upon which the said annual premiums will be awarded.

Conditions of the Magellanic Premium.

1. The candidate shall send his discovery, invention or improvement, addressed to the President, or one of the Vice-Presidents of the Society, free of postage or other charges, and shall distinguish his performance by some motto, device or other signature, at his pleasure. Together with his discovery, invention or improvement, he shall also send a sealed letter containing the same motto, device or signature, and subscribed with the real name and place of residence of the author.

2. Persons of any nation, sect or denomination whatever shall be admitted as candidates for this premium.

3. No discovery, invention or improvement shall be entitled to this premium which hath been already published or for which the author hath been publicly rewarded elsewhere.

4. The candidate shall communicate his discovery, invention or improvement either in English, French, German or Latin language.

5. All such communications shall be publicly read or exhibited to the Society at some stated meeting, not less than one month previous to the day of adjudication, and shall at all times be open to the inspection of such members as shall desire it. But no member shall carry home with him any communication, description or model, except the officer to whom it shall be intrusted ; nor

shall such officer part with the same out of his custody without a special order of the Society for that purpose.

6. The Society, having previously referred the several communications from candidates for the premium then pending to the consideration of the twelve counselors and other officers of the Society, and having received their report thereon, shall, at one of their stated meetings in the month of December, annually, after the expiration (of this current year of the time and place, together with the particular occasion of which meeting, due notice shall be previously given by public advertisement), proceed to final adjudication of the said premium; and, after due consideration had, a vote shall first be taken on this question, viz. Whether any of the communications then under inspection be worthy of the proposed premium? If this question be determined in the negative, the whole business shall be deferred till another year; but, if in the affirmative, the Society shall proceed to determine by ballot, given by the members at large, the discovery, invention or improvement most useful and worthy; and that discovery, invention or improvement which shall be found to have a majority of concurring votes in its favor shall be successful; and then, and not till then, the sealed letter accompanying the crowned performance shall be opened, and the name of the author announced as the person entitled to the said premium.

7. No member of the Society who is a candidate for the premium then depending, or who hath not previously declared to the Society that he has considered and weighed, according to the best of his judgment, the comparative merits of the several claims then under consideration, shall sit in judgment, or give his vote in awarding the said premium.

8. A full account of the crowned subject shall be published by the Society, as soon as may be after the adjudication, either in a separate publication, or in the next succeeding volume of their Transactions, or in both.

9. The successful performances shall remain under consideration, and their authors be considered as candidates for the premium for five years next succeeding the time of their presentment; except such performances as their authors may, in the meantime, think fit to withdraw. And the Society shall annually publish an abstract of the titles, objects, or subject-matter of the communications, so under consideration; such only excepted as the Society shall think not worthy of public notice.

10. The letters containing the names of authors whose performances shall be rejected, or which shall be found unsuccessful after a trial of five years, shall be burnt before the Society, without breaking the seals.

11. In case there should be a failure, in any year, of any communication worthy of the proposed premium, there will then be two premiums to be awarded the next year. But no accumulation of premiums shall entitle the author to more than one premium for any one discovery, invention or improvement.

12. The premium shall consist of an oval plate of solid standard gold of the value of ten guineas. On one side thereof shall be neatly engraved a short Latin motto suited to the occasion, together with the words: "The Premium of John Hyacinth de Magellan, of London, established in the year 1786"; and on

the other side of the plate shall be engraved these words: "Awarded by the A. P. S. for the discovery of —— A. D. ——." And the seal of the Society shall be annexed to the medal by a ribbon passing through a small hole at the lower edge thereof.

SECTION 2. The Magellanic fund of two hundred guineas shall be considered as ten hundred and fifty dollars, and shall be invested separately from other funds belonging to or under the care of the Society, and a separate and distinct account of it shall be kept by the treasurer.

The said fund shall be credited with the sum of one hundred dollars, to represent the two premiums for which the Society is now liable.

The treasurer shall credit the said fund with interest received on the investment thereof, and, if any surplus of said interest shall remain after providing for the premiums which may then be demandable, said surplus shall be used by the Society for making publication of the terms of the said premiums, and for the addition, to the said premium, of such amount as the Society may from time to time think suitable, or for the institution of other premiums.

The treasurer shall at the first stated meeting of the Society in the month of December annually, make a report of the said fund and of the investment thereof.

Vol. IX., No. 2. 1883. Whole No. 24.

PROCEEDINGS

OF THE

UNITED STATES

NAVAL INSTITUTE.

VOLUME IX.

PUBLISHED QUARTERLY BY THE INSTITUTE.

ANNAPOLIS, MD.

Press of Isaac Friedenwald
Baltimore, Md.

BOSTON, *March* 14, 1883.

LIEUT. J. B. MURDOCK, U. S. N.,

Corresponding Secretary, &c., Annapolis, Md.

DEAR SIR :—The undersigned, in performance of the duty assigned to them by the Executive Committee of the United States Naval Institute, as judges to determine to whom should be awarded the prize and gold medal offered by that Association for the best essay submitted in its competition for the year 1883, upon the following subject, " How may the sphere of usefulness of naval officers be extended in time of peace with advantage to the country and the naval service," unanimously recommend that the award be made to the author of the essay with the motto " Pour encourager les autres." The judges also consider worthy of honorable mention the two essays under the following mottoes respectively : " Semper paratus " and " Cuilibet in arte suâ credendum est." It is proper to state that all the judges do not adopt in full the recommendations and arguments of these essays in recognizing the ability and felicity of their presentation.

Very respectfully yours,

ALEXANDER H. RICE,
J. G. ABBOTT,
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HOW MAY THE SPHERE OF USEFULNESS OF NAVAL OFFICERS BE EXTENDED IN TIME OF PEACE WITH ADVANTAGE TO THE COUNTRY AND THE NAVAL SERVICE?

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PRIZE ESSAY.

"*Pour encourager les autres.*"

I.

The extension of the usefulness of naval officers has recently become a matter of vital importance to the naval service of the future. The reduction in the number of officers of various grades, made during the last session of Congress, has seriously injured the prospects of the officers of the rising generation. More sweeping action in the same direction will tend to crush the hopes and paralyze the activity of all the junior grades of the service. But there can be no security against such action until the usefulness of naval officers becomes a fact admitted by the organs and representatives of public opinion. There is an evident disproportion between the number of officers and

the force of seamen. The disparity between our fleet of valid men-of-war and the list of officers of rank is still more striking. These facts have been held to create a presumption that the corps of officers required reduction. Similar comparisons will continue to supply arguments for further retrenchment unless our fleet shall receive an unlooked-for increase. Two cruisers, with the possible addition of a few monitors unfit for sea service, will hardly suffice to remove the disparity even after the various grades of the navy have been reduced to the numbers authorized by the Naval Appropriation Bill of 1882.

It may, indeed, be pointed out that such disparities are incident to our national policy of maintaining reduced armaments in time of peace. The creation of a war navy for the United States must involve not only the training of a large force of seamen and the construction of a fleet, but also a complete transformation of the methods and appliances heretofore provided for these purposes. For this vast work a large and highly educated force of officers will be required. Such a force has never been improvised in any country, and the decadence of our maritime industries forbids any hope that it might be improvised here.

Our mercantile marine was much larger and more prosperous in 1861 than it is now, and it furnished some thousands of officers for the navy. But the work of organization, the technical and scientific details, and the higher commands, were necessarily assigned to the regularly trained officers who had not abandoned the service of the country.

The large number of such officers who were led to take part in the rebellion were also able to demonstrate the efficiency of the training which they had received, even when employed in defending a hopeless cause. They improvised considerable forces for aggression and for defense in States almost destitute of shipping, seamen and maritime industries. The service from which their training was derived can now afford to recognize with melancholy pride the skill and energy which enabled them to continue the struggle so long.

Reliance upon feeble maritime industries for the material resources of defense may involve delay and disaster in the event of war. Reliance upon a prostrate mercantile marine for officers to develop and employ these resources would certainly involve defeat. Any scheme which attempts to secure an exact correspondence between the number of officers and the ships and material of our navy, at its present

stage, must tend to demoralize the service and may lead to its abolition.

Although these considerations may be recognized so generally that further reductions need not be apprehended, the navy can never secure the support required to prepare it for the highest usefulness in time of war until the usefulness and importance of its services in time of peace are also admitted. So long as it is authoritatively stated and extensively believed that a large part of its officers are spending their time in idleness or in the performance of needless and trifling tasks, the navy will fail to hold its proper place in public estimation. While these statements are largely based upon wilful misconceptions or ignorance, it will be the effort of this essay to suggest means for removing all grounds for the reproach so freely made.

Our present cruising fleet actually requires less than one-half the officers of the navy to man its vessels. The fact that more than one-half are embarked in them involves certain discomforts to all of them, and tends to exclude the younger officers from all important and responsible duties. Every officer is compelled to spend so many years in performing the same duties that he is apt to allow himself to fall into habits of routine unfavorable to mental growth, and incapable of promoting readiness for emergencies which are certain to arise in peace and still more in war. Duties assigned merely as exercises fail to develop the sense of responsibility which should be a controlling force in the education of the young officer for the higher duties of his profession.

The fact that nearly all our ships belong to more or less obsolete types, imposes further limitations upon the value of the experience acquired at sea. In construction, in motive power, and in armament they differ totally from the vessels which we would be compelled to employ in order to meet our weakest possible enemy upon equal terms on the ocean. The management of these obsolete vessels requires skill and training, but the control of efficient men-of-war is not less difficult, and involves complex details which require enlarged experience and special study.

In spite of the drawbacks due to delayed responsibility, the benumbing effects of repetition and routine, and the obsolete character of our naval material, the time spent at sea must be beneficial to those officers who have a share in the responsible work of sailing and navigating the vessels in which they serve. Occasions must arise for the exercise of prompt decision and cool judgment, and the daily applica-

tion of the scientific knowledge which has been the object of previous education makes that education a practical reality. It cannot, therefore, be deemed advisable to withdraw officers from service which may afford them opportunities of such essential value.

Duties to which naval officers may be assigned on shore vary greatly in their importance to the service, and in their effects upon those thus employed. While many officers are engaged in work of the highest value, developing their faculties and enlarging their knowledge, others are condemned to carry out a wearisome routine during their terms of shore duty. Some of them find their time imperfectly occupied, and more find themselves losing the capacity for active mental effort. Were all of them placed in positions where they could do as much for the good of the service and for their own professional and intellectual improvement as a number of those assigned to shore duty have done in recent years, there would be no occasion to discuss any plan for modifying the present system of assignment during the intervals of sea service. But some officers are assigned to duty at navy-yards or on board receiving-ships, where no amount of zeal or ability could elevate the clerical duties performed above those of an entry clerk, or the executive duties above those of a night-watchman. The routine is not less irksome where the duties are of trifling importance, nor are the least capable and willing officers always assigned to the least important places. The detail of officers is often dependent upon conditions similar to those which permit the rain to fall upon the just and the unjust.

It has been proposed as a remedy for this state of affairs that many officers should be placed upon waiting orders, or upon furlough, after completing a cruise. Any action involving pecuniary hardship and not based upon specified grounds in each individual case must often cause injustice. Idleness, associated with humiliation and privation, would drive many of the most capable officers from the service, and would tend to demoralize those who remained. Fortunately the law did not go to the extremities proposed.

A general survey of the present employment of naval officers seems to show that most of them suffer from want of opportunities for professional improvement and from too much dependence upon routine and obsolete methods. Responsibilities come too late in life to be effective in promoting intellectual activity and professional pride, both of which should be principal factors in preparing officers for usefulness in the upper grades of the service. Officers are carefully educated to

perform the duties of midshipmen, and they serve a long apprenticeship before they are allowed to perform those of lieutenants. But they do not receive instruction or training for the specific purpose of fitting them to perform the duties of independent commands, and they will hereafter reach such commands at ages which must render learning new methods very hard work.

The want of mental activity and professional earnestness due to the prevailing conditions is shown in various ways. The periodicals published specially for the use of officers of the army and navy reflect, to some extent, the mental habits and tastes of their patrons. They frequently contain articles written by naval officers. Some of these productions are signed and others are anonymous, and many of them possess considerable merit. Still the prevailing characteristic of this literature, as a whole, may be described as a tendency to amateurishness. A few writers attempt the solution of practical problems of naval warfare by scientific and modern methods. Others persistently separate science from its applications, or practice from the principles which should regulate it. Some indulge in the feeble antiquarianism of a pre-scientific period or the gossip of a frivolous society. Whether dusty with age or spiced with scandal, articles which may be assigned to the class of "old wives' tales" do not belong to the present age, or to the literature of a service which must study the transformation of its methods and material as a condition of its future usefulness and of its very existence.

Under existing conditions, a certain amount of dissipation is so natural that it may fairly be treated as excusable. While proper means should be applied to prevent unreasonable and injurious excesses and to rid the service of those who render themselves unfit to do its work, the main remedy must be sought in improved conditions, especially in those which tend to promote intellectual activity and occupation. It has been shown that indulgence in the most debasing forms of vice is directly affected by such mental conditions. It may be hoped that improvement in this direction will tend also to prevent naval officers from risking their hard-earned savings in mining stocks, or in other ventures less frequently recommended in the columns of religious and other newspapers. In alluding to these subjects it is simply intended to call attention to the importance of checking the waste of energy which may result from the want of healthy interests and activities.

In seeking for channels by which the capacities of naval officers

may be made available for the benefit of the country, the instincts of the naval officer who accepts the obligations of his position will tend to make him measure the interests of the public service very largely by what he knows of the interests of the navy, and he will judge of the usefulness of his employment in time of peace in connection with the probable effect it may have upon his fitness for service in war.

It may be stated that any plan for extending the usefulness of naval officers in time of peace is affected by the three following considerations:

1. Their employment must be essentially useful or productive.
2. It must tend to promote responsibility and mental activity.
3. It must enable them to acquire knowledge which may be usefully applied in connection with their regular naval duties.

These considerations taken together exclude some fields of usefulness which might seem to invite the services of carefully educated young men, devoted to the interests of the country, and liberated from some of the disadvantages which are felt by those whose connection with the public service depends upon personal or partisan influence. Naval officers should not try to make themselves essential parts of any other service than that for which they have been trained, nor should they separate themselves from its active duties until they have acquired the experience necessary for their efficient performance.

Employment outside the regular system of the navy should be assigned with the purpose of utilizing and developing special qualifications and individual aptitudes. This principle cannot be fully applied to details for regular service in time of peace, but it should not be ignored altogether, and it must govern the selection of officers for important duties in the event of war or other emergencies. *La carrière ouverte aux talents* was the maxim which swept through Europe with the impulse of the French Revolution and the eagles of Napoleon.

This principle requires recognition in the execution of any plan to educate and train naval officers for the highest usefulness in any field. It is generally held that each generation of naval officers should be made to acquire all the knowledge and skill of their predecessors, without rejecting what has become obsolete through the employment of improved methods. This having been accomplished, the officer is allowed to crown the work with a general knowledge of the improved systems of the present day. It is plain that advanced knowledge in any field implies the selection of some subjects to the partial exclusion

of others. This is more than ever the case when a complete change in essential matters relating to naval warfare takes place every ten or fifteen years.

Even in the last century there were some who were bold enough to take up specialties in the naval profession and to prefer them to what have always been considered the foundations of all naval training. Among those who made such a choice was Nelson, of whom Sir Edward Codrington, who greatly admired him and who commanded a seventy-four at Trafalgar and the allied fleets at Navarino, said, while comparing him with another distinguished Admiral: "Lord Exmouth was remarkable for that gift of ready resource and wonderful personal activity which we look for in what we call a good seaman, but he was not born to command a fleet. Lord Nelson, on the contrary, was no seaman; even in the earlier stages of the profession his genius had soared higher and all his energies were turned to becoming a great commander. He had probably always been occupied in planning manœuvres and modes of attack with a fleet."

It required Nelson's genius to justify the choice he made by a career of brilliant success. It is not intended to assert that such a choice is open to young officers at the present day. But there must be a selection, implying the rejection of some subjects, if a high standard of excellence is to be attained in any profession so comprehensive and so subject to change as that of a naval officer. This necessity should be recognized in establishing systems of naval training and in detailing officers for duty in extended fields of usefulness.

II.

In seeking to extend the sphere of usefulness of naval officers, it has been assumed that every suitable employment will afford opportunities for increased professional knowledge and experience. All such employments are, in the largest sense of the word, educational. In the customary and restricted sense also education seems to be a necessary preliminary to employment in the higher fields of usefulness.

Naval officers are carefully and liberally educated before they enter upon the active duties of their profession. But the limited qualifications required for admission to the Naval Academy, the number of technical subjects, exercises and drills, and the requirements of military discipline, combine to limit the scope of mental cultivation and attainments already restricted by the youth of the

students. The uniformity of the courses of study and the hurried progress through the long list of branches taken up, confine the student to his text-books and forbid him to complete his knowledge of those subjects for which he may have a special taste and capacity. If the fidelity of instructors and the stimulus of competition make his progress thorough, it is still lacking in opportunities for original investigation or for practical application of the scientific knowledge acquired.

Nor are these opportunities often found in the ordinary round of naval duties. The requirements of examining boards also fail to encourage such investigations and applications as might be expected from officers educated with so much care as the graduates of the Naval Academy. Examinations preliminary to promotion are properly restricted to those elementary subjects which all have equal opportunities for mastering. Moreover, examinations of this kind are becoming such infrequent events in the lives of naval officers that their influence is only slightly felt.

Officers employed in designing, constructing, or testing new arms, machinery, or vessels, in making surveys and explorations, or in work of like character, do indeed make extensive applications of the knowledge of mathematics and physics which they have been able to acquire and retain. They often find it necessary to take up elementary studies in order to fit themselves for useful work, and in nearly every case they find large gaps between their available knowledge and the practical problems which they are called upon to solve. The filling of these gaps requires time needed for work or for recreation, and the amount of work done may be lessened or its value impaired on account of imperfect knowledge. Original investigation should be connected with duties of the classes under consideration, but such investigations require time and special training as well as apparatus, which cannot be applied by those actively and constantly employed.

It would seem that there would be economy in separating the study and training which most officers need to fit themselves for special work, from the period of actual assignment to such duties. Opportunities for reviewing studies previously gone over should be connected with investigations and experiments tending to connect those studies with their practical applications. What may be called connective courses will be required by some, while others will need to be introduced to new and improved processes which the advance of

science has made available since their scholastic training was completed. Every course of study offered to intending students should be arranged to fit the special abilities of those who may avail themselves of it, and to prepare them for special employment in definite fields. They will thus become more promptly and completely adapted to the various useful occupations which are now open to naval officers or to which they may hereafter be assigned.

To regulate the courses of study which should be authorized, a responsible board or a single officer of high qualifications will be required. English experience seems to be in favor of the appointment of a Director of Studies, authorized to refer special subjects to those best qualified to decide upon them. The Bureau of Navigation would naturally be the one with which such a system would be connected, with proper arrangements for referring to other bureaus, or to the Academic Board of the Naval Academy in special cases where technical or scientific information was required.

The Director of Studies might communicate to the service, through the proper channels, a programme explaining his plans and the methods proposed for carrying them out. A list of proposed branches should be appended, with suggestions to enable applicants to combine and select them according to their special objects and state of preparation. Preliminary applications might then be made for permission to take up courses of study during the intervals of active employment. Such applications should contain detailed statements of the ends and means which candidates desire for themselves. Present acquirements should be frankly exposed, and letters of advice suggesting such preparatory studies and reading as may be taken up by those to whom they are addressed, should be issued by the Director of Studies.

When any applicant has completed his term of active duty he should make a final application, and his qualifications should be tested before he is assigned to his proposed work. Examinations, written or oral, would be the means of determining this. Written examinations might be conducted by letter, or the candidate might merely be required to send in a paper showing original research in his special subject. Evidence of special aptitude and earnest purpose would be the main requisite to enable the Director of Studies to make a favorable decision. This decision should assign the candidate to a course of study, to means of instruction and a place of residence, subject to the approval of the Secretary of the Navy.

The question of residence and means of instruction should be decided for each applicant in accordance with his circumstances and wishes, as far as they can be reconciled with the objects proposed. Many officers would gladly go on leave for a definite period to take the course assigned to them. Others would have to be ordered to duty at the places where they could work to best advantage. The Naval Academy, universities of established reputation, industrial establishments or governmental institutions might all present the facilities desired by candidates of various classes. Residence abroad might be necessary to enable some to carry out their plans. The importance of their purposes and the results promised should be weighed in determining the method of assignment. In cases where expense to the department would be involved, a preliminary course on leave might supply a test of the propriety of incurring it. Travelling expenses and other duty pay should not be withheld from those whose efforts are likely to benefit the service or the country.

It may be urged that the establishment of post-graduate courses at the Naval Academy would satisfy all the conditions requisite for success. But the object of the plan being to secure varied attainments, the limited range of branches for which the Naval Academy offers advantages will not be sufficient for all. Many of the officers who take these advanced courses will hereafter be instructors at the Naval Academy. To secure the best results they should be brought into contact with broader methods and ideas than can be fully applied in that institution. In-and-in breeding never succeeds in the long run, but fresh blood is needed in every system to secure soundness and vigor. The practical difficulties due to differences in age and rank would also be felt. Uniformity in treatment and the restraints of discipline necessary in such a school cannot readily be applied to officers of various grades and acquirements. They might be found obstructive to earnest students and irritating to men of mature years. The class system does not apply to the objects proposed. The association of a number of young officers might result in the establishment of an easy routine of study, or, if competition were introduced to prevent this, might repeat or intensify some of the animosities and injustices with which former unfair competitions have afflicted some grades in the service.

Discretion would be necessary in selecting officers to be allowed the advantages proposed. Taking very young officers might make these courses mere continuations of the regular school studies of the

naval cadet, pursued without practical purpose and tending to exaggerate the defects due to protracted scholastic training. Officers of more mature years and larger experience would generally have some well-considered purpose in view, and would not be in danger of losing all professional habits and ideas while carrying out their plans. A careful inquiry into the nurture and training of men of scientific eminence in England showed that few of them could connect their progress in their special branches of knowledge with their school education. Most of them had some experience in practical life before they devoted themselves to their special work, to which they were led by their surroundings or by matured judgment. On the other hand, young men learn with greater ease, and recent graduates of our schools have much less ground to make up than their seniors. If only those are excluded from these opportunities who have not had time to identify themselves with the service and to become familiar with its duties, or who are unfitted by age, infirmities or habits from the fullest mental activity, good results may be anticipated from the rest.

The choice of studies made by the officers applying for permission to make use of these opportunities should be revised by a responsible officer and adjusted to the capacities of the applicants and the needs of the service. The thorough-going specialist might be left to his subject, with suggestions in regard to the methods to be followed and the results to be sought. In most cases, however, one study might be accepted as the principal object of the course, and others combined with it. The main study should, in all cases, be capable of useful application to the improvement of the navy, and should qualify the student for active employment in a specified field of usefulness. Both the necessary preparation and the practical application of this central subject should be insisted upon throughout. Minor studies of contingent usefulness might be permitted when suggested by individual tastes and aptitudes.

The studies which are capable of useful applications in the navy or other branches of the public service may be classed in two principal groups, of which the most important includes the mathematical and physical sciences and their practical applications. The importance of these sciences in solving nautical and technical problems is evident. Each science should be studied with direct reference to its uses, and the absurd separation of theory and practice should not be tolerated. No advanced course in gunnery, navigation or steam engineering is

possible without scientific knowledge. Any merely operative course will be imperfect in its methods and barren in its results. Nor should the student be allowed to confine himself to pure science or mathematics, or to waste his time in solving imaginary problems. The man who devotes himself to working out the theory of probabilities or any other unpractical subject will hardly fit himself for usefulness as a naval officer. The failure of the purely practical man when called upon to apply and control new and complex forces and machinery will be inevitable and perhaps dangerous.

The inventor whose stock in trade consists in a little mechanical ingenuity and a great deal of self-confidence is a person to be pitied. Give him a plausible manner, a talent for drawing, and good backers, and set him to work at guns, torpedoes or engines for men-of-war, and he becomes a person to be feared. If he can be made to study mathematics and mechanics until he is capable of calculating the limits of practical efficiency and the strength of material for each portion of his inventions, his fertility in new and strange devices will be moderated, and he may become harmless and even a highly useful member of society.

Dr. Siemens, whose scientific knowledge has created an enormous amount of concrete wealth, took occasion, in his address as President of the British Association last summer, to point out that, for every application of physical forces, it is necessary to compute the theoretical standard of efficiency to prevent the waste of time and energy in seeking an impossible result or in accepting an imperfect one. The straight line must be traced and the curve brought as near it as possible.

Mathematics, as applied to nautical astronomy, navigation, or surveying; mechanics, in connection with gunnery, naval construction and steam engineering; chemistry, in connection with explosives, the corrosion of materials, or photography, are all fields for students and investigators. Opportunities for learning various branches of natural history have recently been offered to a number of young officers. The eagerness with which they have been accepted and improved, and the fact that by them officers are prepared to do valuable work in connection with active duties in the vessels of the Fish Commission or in men-of-war engaged in making surveys and explorations, furnish strong arguments for the continuance of the system, and for the extension of similar opportunities to those who desire to improve themselves in other branches of knowledge even more nearly related

to their practical and professional duties. It may be advisable to take some precautions to prevent very young officers from becoming engrossed in scientific pursuits before they have learned to identify themselves with the service which has the strongest claim to them and their talents.

One of the advantages which may be anticipated from the training of naval officers will be realized when our national museums shall have received valuable collections or specimens prepared and arranged in such a manner that they can be used for reference by specialists, without any of the uncertainties which render objects picked up as mere curiosities so nearly worthless. The practical value of museums of natural history, ethnology and antiquity, in promoting education, the progress of the useful arts and the elevation of the people, is now generally recognized. The opportunities enjoyed by naval officers for making valuable additions to these collections are often lost for want of interest and taste developed by study and observation. The broadest and most varied culture might often be made available were the national importance of the work recognized.

These considerations draw our attention to the second great group of studies, of which history, languages, and law are leading members. Here, even more than in the scientific group, special capacities should be considered before assigning courses of study to those who apply. They lie mostly outside the list of absolute essentials to the working naval officer, but each class offers inducements to those who seek extended usefulness in time of peace, and most of them must have their special students to make the navy a complete working organization.

History shows the value of discipline and patriotic purposes in those who serve the public; it furnishes the student of naval warfare with examples of practical importance; and it supplies the knowledge of foreign institutions and customs which is often indispensable to those who may be called upon to represent their government in transacting public business. The study of language promises even more direct benefits to the public service. Naval officers must know something of international law to conduct themselves with safety and propriety in dealing with foreign authorities and protecting national interests. Municipal law is also a branch of which those who are frequently called upon to act as magistrates cannot afford to remain ignorant. Political economy, social science, and even some knowledge of literature and art may each and all be found practically

useful upon occasion. The ability to observe correctly and describe clearly the social, economical and industrial condition of countries visited may be of great value to the nation, and preparation for such services should certainly be encouraged.

Distinguished naval officers of all countries have cultivated tastes and abilities quite as remote from their every-day employments as those which have been specified. Nelson went to France to study the language during the only interval of peace in his naval career. One of the distinguished Napier family was occupied for many years after the close of a creditable record of service at sea, in writing the History of Florence. Commodore Charles Morris of our own service applied himself earnestly to the study of general history and modern languages. Dumont d'Urville owed the opportunity of rendering what was, perhaps, his most memorable service to France, to the archæological knowledge or artistic taste which enabled him to recognize the value of the noble statue called the Venus of Milo, which is still one of the choicest treasures owned by the French republic.

Perhaps the course in law is the only one of this group which should be admitted as a principal or independent one. History, the languages, and the other branches noticed might be recognized as auxiliary or secondary subjects where they supplemented the other studies authorized, or seemed adapted to the special talents of any student. French and German are necessary to any one taking a thorough course in almost any science or technical subject. Italian also would be useful in many cases. Every student who is permitted to go abroad should be required to learn to speak at least one language with facility. In exceptional cases it might be well to encourage the study of languages so widely distributed as the Arabic, Chinese, Malay or those of the Polynesian family. The English Admiralty offers substantial rewards to those officers who qualify themselves to act as interpreters in such languages, and it is evident that such knowledge might be of the greatest value to a military or exploring expedition.

A course of study having been assigned, it is next in order to consider how it is to be carried on and how long it may last. Leave or orders for students might be made out for periods of six months, and at the expiration of each period all of them should be required to report progress. The results of special investigations, solutions of problems, and papers upon subjects in the course followed, should be sent in, and full statements in regard to reading, lectures, and prac-

tice should be made. In promising cases the course might be extended to one or even two years. An officer who had done good work on leave might be given opportunities for further progress, by assignment under orders to places where the proper facilities could be obtained. Of course any officer would at all times be subject to detail for naval duties, and no course of study should be continued after any evidence of neglect or indifference to its advantages on the part of the officer allowed to take it up had been discovered. Full particulars of the studies pursued and the results obtained should be recorded in the Office of Intelligence or some other suitable place, and this record should be consulted when officers are to be selected for special duties.

The scheme for promoting advanced education among naval officers here presented is intimately connected with the proposed employments to be hereafter discussed. It does not involve much expense, and the only rewards it promises are congenial and useful occupation to those who take advantage of it and acquit themselves with credit. Such contingent advantages will hardly attract any one without a distinct purpose and a special aptitude for work. Similar methods of encouraging study are pursued in foreign service, and in the medical department of our own, with considerable profit to all who come under their influence.

III.

The organization of the Light-house Board and its successful operations during the last thirty years attest the benefits resulting from the employment of naval officers outside of the regular duties of the service. The distinguished officer whose energy and intelligence secured these opportunities of usefulness to succeeding generations of naval officers, is still among us. His victory over obstinate routine and prejudice secured results of equal value to the navy and the country. The present efficiency of the Light-house system is due to him and to the faithful and intelligent officers who have succeeded him in this great work. There is little danger that these opportunities will be withdrawn from naval officers. It is to be hoped that they may be extended to afford employment to a larger number of officers, and to connect them with the service in such a manner that even better work may be done in the future.

This may be done by ordering one or more assistants to each naval inspector of a light-house district. They should be attached to the

steam-tenders, and should be required to acquaint themselves with all the details of the service, and with all the waters lighted or buoyed in their respective districts. They should be made useful in navigating the vessels, in keeping them in order, and in superintending repairs to them or their equipments, or to any other part of the material which they might be found qualified to control. Their employment in these fields would be in the interests of economy and efficiency. Superintendents of repairs are now appointed whenever work of any importance is undertaken, and their compensation often forms a large percentage of its total cost. But the main object of detailing junior officers for this work would be to train a corps of inspectors for future usefulness. The details of the operations in the more important districts can hardly be mastered in a short time by the most zealous officer, and there is danger that too many of them may fall into the hands of subordinates, and be imperfectly or extravagantly performed. The benefits which would result to the navy from the employment of young and active officers in managing vessels on our own coast, where they would be compelled to learn the art of pilotage, cannot be questioned.

Naval officers have also been creditably and usefully engaged in the work of the Coast Survey since its inauguration. The important services rendered and the valuable knowledge acquired in this field have been recognized by competent authorities, and by the navy at large. Recent successes in the prosecution of scientific work have been due to the efforts of intelligent and skilful naval officers, who have conferred credit upon themselves, upon the Coast Survey, and upon the navy, and have done work which will benefit the country and the world.

Under these conditions it is only necessary to insist that this present connection should be maintained and strengthened, and to suggest that the regular instruction in the various branches of marine surveying should be recognized by the authorities of the Coast Survey as a means of securing larger and better results from naval officers assigned to vessels of the Coast Survey, and as a partial return for the expense incurred by the Navy Department in supplying men and officers to man these vessels. A simple and comprehensive manual, explaining the methods in actual use, would, when placed in the hands of well-grounded naval officers, be almost all that would be required. A little personal instruction during the intervals of active employment and occasional changes in the character of the duties

assigned to each officer, would fit them to render important services to the navy, and prepare them for future usefulness in the Coast Survey. No officer should be allowed to waste his time in ship-keeping or waiting for repairs, and professional jealousies should not be allowed to deprive him of opportunities for learning to employ his time to advantage. The Coast Survey might justly insist upon a certain amount of preparation from officers assigned to duty in its vessels; and the Navy Department might, with equal justice, require each officer who has completed a tour of duty to show that he has learned something of surveying in all its branches, and of the pilotage of the waters where he has been engaged in carrying on work.

The work of the Fish Commission satisfies the conditions upon which the employment of naval officers outside of their regular naval work should be dependent. It gives them useful work to do; it encourages and develops study and mental progress; it affords them larger opportunities for handling sea-going vessels than they can hope to enjoy while they remain in the junior grades of the navy. The nautical experience of naval officers, and their general education combined with the special instruction now accessible to some of them, should make them useful auxiliaries in the important work of this branch of the public service. If officers, whose attention has been drawn to problems in connection with the practical work of the fisheries, are given the advantages afforded by the courses of the Smithsonian Institution, excellent results may be expected.

In all the branches of the public service which have been mentioned, the usefulness of naval officers has been demonstrated. The country has received direct benefits from their employment in these fields, and the navy has shared in these benefits. It is believed, however, that larger and more useful results might be secured by extending the authority of the Navy Department, so that all the strictly maritime work of the government should be under its supervision. Naval officers employed in any one of these branches would be encouraged to improve their opportunities to the utmost, if the Department, which must regulate their employment and advancement in future, was controlling and recording the work in which they were engaged. The fact that no real school of nautical science exists except at Annapolis, and that imitations of the Naval Academy must be organized before any branch of the public service can secure qualified officers to take charge of its maritime work, justifies the assertion that economy and efficiency would result from extending

the sphere of usefulness of naval officers until they have a share in all work of that class.

These considerations apply to the Revenue Marine and to the Life Saving Service. There will be few openings for naval officers in the former until some years after the proposed transfer to the Navy Department has been made. In the Life Saving Service there should be no delay in allowing naval officers to have a share in administrative duties. Their exclusion under the present system is invidious and not in the interest of the public service. Officers of the Revenue Marine regulate the nautical part of its operations, and officers of the army are called in to experiment and report upon its ordnance. The respectable attainments and experience of naval officers in both departments are ignored. They have unequalled opportunities to study the merits of similar organizations in other countries, and to observe the conditions of safety in boating under all circumstances. Their personal interests make the efficient working of the Life Saving Service a matter of importance to each one of them. Finally, they are qualified to assist in emancipating this service from the political influences which have hindered its progress toward a high standard of discipline and success.

One of the largest, most varied, and most promising fields of usefulness for naval officers will be found in the administrative services, established and proposed, for the regulation of the mercantile marine. This industry has great importance in an economical and commercial sense, and its present condition of decay is a public misfortune. As long as the country is compelled to rely upon the resources of merchant shipping for defensive strength in time of war, their decadence is a public danger. Naval officers have special qualifications for conducting the investigations and carrying out the reforms which are essential to arrest the maritime decadence which has gone so far. For acquiring the information and suggesting the means by which the defensive resources of our maritime industries may be utilized and developed for future emergencies, no other branch of the public service can ever be made available. The establishment of a Bureau of Mercantile Marine under the Navy Department supplies the most simple and economical organization which can be devised to carry out the necessary administrative reforms. Even if a different organization shall be preferred, the services of naval officers can hardly be dispensed with if real progress is to be effected.

As an important auxiliary to any bureau or department which may undertake to regulate the scattered and defective services which

divide the control of our maritime industries, a permanent advisory commission should be constituted, of representatives of the maritime and commercial interests of the country, assisted by naval officers of special experience and ability. Such a board should be employed in investigating the needs of shipping, and in framing regulations, subject to the approval of the responsible head of the department, for promoting its sound and vigorous growth. The demands of the mercantile community for an organization through which their wants and wishes can be communicated to the authorities charged with the supervision of shipping would be met by the establishment of a properly constituted mercantile marine board.

Such a board would replace the curious organization known as the Board of Supervising Inspectors, which now meets annually to enact rules for the navigation of all steamers in our waters, and to impose requirements for their inspection by the local boards appointed for the purpose. The members of this board are also executive officers supervising the inspection service in the respective districts assigned to them at their annual meetings. As a board, also, they receive their individual reports and act upon them when presented. The mutual self-approval which is the natural result of this arrangement, excites the vigorous criticism of the supervising inspector-general, but his denunciations do not disturb the established methods.

The local boards of inspectors are nominated by strangely constituted boards, of which district judges and collectors of customs are members. The inspector of hulls, who should know something of shipbuilding, and the inspector of boilers, who must be an engineer, not only act together in inspecting and licensing steamers, but also in examining and licensing all masters, mates, pilots and engineers of steam vessels. The necessity for an inspector of navigation, qualified to report upon the compasses and navigating outfit supplied to each vessel, and to examine officers in navigation and seamanship, is self-evident.

The employment of naval officers in the steamboat inspection service would facilitate the reorganization needed to give it the discipline and the nautical and progressive character, without which it must be an obstacle to the revival of our mercantile marine. As long as it devotes its entire attention to the subject of regulations for the prevention of such boiler explosions as were once common on our western rivers, and to the imposition of dangerous and useless patented devices for life-saving purposes, while neglecting the means necessary

to secure the safe navigation of steamers on the high seas, it will obstruct and discourage the employment of American steamers in our foreign trade. The employment of naval officers without extra compensation would be a measure of economy, and might lead to the reduction of the exorbitant fees now exacted. It might also lead to the adoption of definite standards and sensible methods for examining officers for licenses, and when this had been accomplished the annual renewal or "sale of license" would be dropped as an absurd and vexatious requirement.

Local boards of inspectors now investigate all accidents to steam vessels and all cases of misconduct on the part of licensed officers. Their lack of qualifications for this responsible task has been shown. Their approval of the material or equipment of a vessel might dispose them to shift the responsibility for any disaster to the officers on board. In general, however, the results of their judicial inquiries are inconclusive, if not worthless. Nor are the occasional investigations conducted by the Life Saving Service based on a sounder system. The safety of vessels and their passengers will be promoted by changes which shall secure prompt investigations by legal methods and by competent and impartial experts in any case of marine disaster. Here again the usefulness of naval officers might be extended by appointing them as assessors to take part in the conduct of judicial inquiries, as has been done in Great Britain, to the satisfaction of law officers, underwriters and the general public.

The unrestrained obstruction of the channels of our most important ports by the dumping of ashes, street-sweepings and dredgings shows a remarkable failure in administration.

Probably some legislation would be necessary to enable the general government to intervene to save the harbors which they have improved at such enormous expense. A few years ago an appropriation of $600,000 was demanded for the removal of shoals in New York harbor which had been thus created. The inability of local authorities to cope with this evil is shown by the fact that, after years of agitation, only one inspector is maintained to look out for thirty miles of water front at New York. The adoption of rules for the control of harbors by the authority of the United States, and the appointment of a qualified naval officer to act as a hydrographic inspector at each of the great seaports, might provide a remedy. Two or three swift steam launches, commanded by active officers, could do the work of policing a very large harbor, and the experience acquired by young officers assigned to such employment would be of great value.

In connection with the proposal to permit officers to carry on courses of study at colleges and universities, it may be found that there would be a demand for the services of some of them as instructors. The detail of naval engineers, as well as that of officers of the army, to serve in such capacities is now authorized by law.

The adoption of the elective system in our leading institutions of learning must tend to produce great variety in the studies and practical applications which will be pursued. It is not improbable that an instructor in navigation and hydrography would find pupils among those who were preparing themselves for commercial life or scientific work in connection with marine biology, physical geography or meteorology. If the teacher was well qualified for his task and disposed to continue to be a learner, great advantages might result to the country and to the navy from details for this purpose.

It may seem that in presenting the claims of so many employments outside the regular naval routine the claims of the service have been neglected. Aside from the further proposals, which will be made in due course, I would point out that much of the work mentioned is of a nautical and professional kind. The detail of officers might be arranged to give nearly every officer the command of a vessel of some kind before reaching the grade of lieutenant-commander. Responsibility might also be made to develop the abilities of naval officers in other posts of duty. An officer of the British army, who has rendered valuable services in controlling the railways of Great Britain, and who has earned reputation as a man of science, in replying to a question similar to the one discussed in this essay, said: "But all duties which place them in situations of responsibility, and where judgment is required, would tend more than anything to draw out their capabilities and improve their efficiency for purposes of war."

If it be objected to all the suggestions which have involved the extension of the employment of naval officers in various branches of the public service, that deserving civilians may thus be deprived of employment, it will be proper to state that no disturbance of claims based upon long and faithful service or upon special training or fitness for the duties of any branch, is contemplated. The navy owes too much to the system which has kept it out of the bondage of political dependence to seek to disturb such a system elsewhere. But it is notorious that very few branches of the public service have recognized such methods of regulating appointments and promotions. Most of

those who would be displaced have owed their positions to other than public considerations. In any case the government, after educating and training its officers at vast expense, has a right to make the best of their professional services in any public employment for which they are qualified.

IV.

The claims of various branches of usefulness outside the field of strictly naval employment have been presented in detail. To make the plan proposed complete and symmetrical, the claims of the naval service must receive equal attention. Officers must still spend most of the active portion of their lives at sea, or in the performance of naval duties on shore. No scheme of extended usefulness can afford to ignore the methods which should render such employments more fruitful and more conducive to mental activity and professional progress. The suggestions which follow are not meant to imply any general criticism of the present methods of carrying on naval duties. Supplementary requirements will be proposed with a view to the improvement of the service and its officers.

Here, as elsewhere, the main idea will be to adjust special duties to special capacities, and to utilize and develop the talents of each naval officer in some definite field. As a means of making those special abilities matters of record, let every officer below a certain rank or a certain age—neither of which should be fixed too low—be required to send to the Department, at least once a year, a report or study upon some subject of professional, scientific, or general interest. Full liberty in the choice and treatment of the subject should be allowed, but serious work should be insisted upon in every case. Surveys of shoals or harbors, sketches of coasts or landmarks, drawings of naval machinery or vessels, records of observations, solutions of problems, suggestions in regard to drill or equipment, collections of photographs or of objects of natural history, should be accepted with quite as much favor as the written reports, translations, or descriptions which might be sent in by the majority of officers. No one form of expression should be exclusively preferred. In every case, however, a full statement of all the authorities consulted and of all the assistance received should accompany the report or study. While compilations and translations may often be works of value, the superior claims of original research should not be ignored.

To ensure success at the beginning, suggestive lists of subjects should accompany the circular stating the requirements of the system.

Such a list should include subjects suitable for treatment by officers of different branches of the service and of different mental habit and training, but no compulsory conditions should be annexed. Upon the receipt of the papers at the department they should be classified and indexed by officers detailed for the purpose. Each paper should be referred to some authority upon its subject for a decision as to its relative merits. A few of the most valuable and suggestive papers should be published, and all should be filed in an accessible and convenient manner. The papers selected for publication should be those which would find the largest audiences among naval officers, and would do most to awaken and stimulate the faculties of others. Some papers of the highest value might fail to be printed under this rule, because they would be interesting only to special students. They would, however, be available for reference at any time. The titles of all papers which were considered to possess special merit should be published with the names of their authors.

It is to be hoped that each year's reports would contain a number of valuable contributions to naval and scientific progress. They would be useful in compiling sailing directions, in revising technical manuals of all kinds, in preparing for the transformation of the vessels and armaments of the navy to modern types fit for war purposes, and in arranging for the attack or defense of coasts and harbors in all parts of the world where our navy might be called upon to act.

They would, moreover, indicate the state of professional knowledge in the navy at the period of their preparation, and would place on record the special qualifications of most naval officers. The files of these papers would be consulted, not only by special students, but also by those desiring to select officers for important services, and by examining boards. No injustice would be done those who have failed to be successful in any form of expression if others were selected for places where facility in employing these forms was a condition of usefulness. Nor would there be any danger that examiners would be unduly influenced by these papers. They might be led to shorten their examinations in many cases, but no candidate showing industry, a good record, and a fair amount of professional knowledge, would have anything to fear.

In the German army examinations for promotion are replaced by the requirement of studies and reports upon professional subjects, by actual tests of fitness for higher command, and by inquiry into the personal records of officers. In the French navy, a system almost

identical with the one here proposed has been carried out for some years, and its principles are applied to some extent in other foreign services. In the medical corps of the navy, officers are required to make reports for publication. It is believed that this requirement has been attended with good results, although the practice of publishing all of them in full is open to some objections on the ground of expense, and need not be imitated.

Among the most important results to be expected from the system of requiring reports and studies from naval officers, is that of turning the attention of our future naval commanders to the military subjects upon which preparation for war service must be based. Navies exist only for the contingencies of war, yet very little of the training of sea officers has any direct reference to these contingencies. Discipline and responsibility do indeed develop some of the most essential qualities of the fighting man, when applied to good material. But the conditions of modern warfare—especially of naval warfare—are so complex and so subject to change, that constant mental training is needed to enable officers to anticipate and prepare for the contingencies of attack and defense. The necessary work of the naval service can very readily be expanded into a vast system of routine for peace purposes which must obstruct every attempt to prepare for war. I have heard it asserted, by those who should have known better, that "the war had ruined the navy"; that is, it had interrupted the peace routine, and had made it difficult, if not impossible, to restore the exact methods and ideas which had grown out of that routine. Strong efforts have been made to ignore every lesson taught by four years of active service, and those who partially accepted the teachings of those years have allowed the material of our navy to come to a dead stop at the point reached in 1865. The advantages of laminated armor, of smoothbore guns, and the general absurdity of iron hulls for men-of-war, were among the lessons taught at the Naval Academy for some years after the close of the civil war.

Obsolete methods in warfare show a tendency to crystallize in text-books and manuals of instruction. The Ordnance Manual in use until 1880 contained the misleading and discouraging statement that "the landing of seamen is rather a remote contingency in the naval service, and should never be resorted to when opposed by good infantry." The edition now in use introduces a chapter on boarding and repelling boarders, by sentences which indicate doubt as to the practical value of rules for the subject, but the detailed instructions

thereon occupy six pages, while the subject of defense against torpedoes is disposed of in three lines, by making it dependent upon the ingenuity of the commander. In speaking of machine-guns and small-arms the precept is laid down that "their principal duty is to clear the way for and support the boarders."

It is evident that the progress of improvement in military weapons requires a constant readjustment of the regulations for drills and exercises. No amount of mechanical perfection will supply the want of intelligent preparation for foreseen emergencies. The watchword of German military training is "preparation for battle," and the most powerful organization for war purposes that the world has ever seen has been created by the scientific study of the art of war. Every officer is required to plan movements in the face of the enemy and to carry them out under conditions closely resembling those of an engagement. Every soldier is taught to do intelligently those things which he would have to do in action. During the war of 1870, German soldiers were frequently heard to remark in the heat of action, "Why, this is just like the exercises we used to have at home." To acquire this practical readiness the parade drills have been simplified as much as possible. The movements which a Prussian regiment is called upon to perform at inspection are few and simple, but each recruit must be a soldier and must know how to do his share of the work of a battle.

The system of reports and studies to which attention has been invited supplies a ready means for developing the military knowledge of naval officers. The attention of line-officers of the navy should be directed to the solution of the actual problems of modern warfare. They should study the turning of ships at full speed to ram or to avoid being rammed by another vessel, the working of naval batteries so that their fire may be made available at full range against an enemy in motion, the mounting of guns to secure an all-round fire without exposing crews to the deadly fire of machine-guns and small-arms, the disposition of naval forces for the attack or defense of particular harbors, the control of a group of torpedo boats in an attack, and the defense of vessels from torpedo attacks where Whiteheads or other formidable weapons are used.

No field of military activity deserves more attention than the handling of landing parties of seamen. The splendid arms carried by our seamen, supplemented by machine-guns of various kinds, the reduction in the size of tactical units, and the enlarged scope of indi-

vidual action admitted and enforced by the conditions of modern war, all combine to increase the value of such forces.

The naval brigades which assisted in the defense of Sebastopol and Paris, and made long and arduous campaigns in South Africa and Egypt, have demonstrated the errors contained in the old and narrow views of the usefulness of seamen. The necessity for observing proper precautions in landing or marching in an enemy's country has also been increased by the changes in arms and methods. Men are often landed in peace as well as in war, and to be prepared for all contingencies officers should learn how to make a reconnoissance, to conduct a march, or to guard a post in a hostile country.

Of course these things cannot be thoroughly learned without opportunities for applying in the field the knowledge acquired by study. The system of practice should be progessive, and, instead of beginning with brigade or battalion drills, officers should land with a company or platoon and should conduct them for a mile or two inland to occupy a position assigned beforehand. Combined movements on a larger scale could then be tried ; but dress parade and barrack square evolutions should not be allowed to occupy the time which is available for these more important exercises. The magnificent harbor of Port Royal offers abundant facilities for exercises of this kind as well as for every other exercise needed to prepare our ships and crews for action. Vessels can be separated from a fleet and assigned positions in which to await an attack from torpedo boats. Targets of any size might be set up on land to give opportunities for observing the effects of different projectiles and kinds of fire. A fleet supplied with a number of military studies of the capabilities for the attack and defense of the system of inland waters around Port Royal might spend a winter in active and profitable exercises.

The study of naval tactics on the high seas may be postponed until fleets capable of manœuvring in action have been constructed or designed. Tempting as such studies are, they can hardly be considered as fruitful or essential at the present time.

When the graduates of our training-ships shall make up the larger portion of the force required to man our vessels, it may be hoped that divisional officers will be able to advance the military training of their best men far beyond the rudimentary state to which they were restricted under the old system of recruiting. The necessity for such advanced training is evident, if the capabilities of the future armaments of our ships are to be practically developed. When the time spent in

teaching raw landsmen the first elements of drill can be devoted to instruction in the actual methods of attack and defense, officers as well as seamen will be benefited and our naval gunnery and small-arm practice will be vastly improved.

Intelligence and education will be found important factors in promoting the coöperation of our seamen in such progress. In other respects a gain in these particulars will be a blessing to the service.

An acute observer, who travelled in the South before the rebellion, and analyzed the fatal vices of the institutions which were destroyed by that event, speaks of visiting the Norfolk Navy Yard and of hearing the officers of one of our men-of-war complain of the wretched character of the recruits with whom they were supplied, and the resulting impossibility of securing a high standard of naval discipline and efficiency. The author, after reflection, concluded that in a certain amount of healthy education the remedy would be found. The social and political changes predicted in his work have largely been realized, but the education of our seamen, with a view to intelligent activity and sound discipline, still leaves room for improvement.

There is a natural tendency to neglect this subject and to accept an imitation of the seaman found in our ships, at some traditional or imaginary period of the past, as the standard article. Marlin-spike seamanship and a sailor-like bearing are matters of some real importance, but they will not make up for obstinate ignorance of everything relating to modern naval warfare, especially when combined with incorrigible drunkenness at every opportunity. Looking at military requirements alone, a certain amount of educated intelligence will be essential to the men who are to handle such complicated engines of war as a rifled gun of large calibre or a modern torpedo.

The value of education as a foundation for military and naval training is recognized in practice by all the warlike nations of Europe. In Germany a young man of good education is allowed to shorten his term of compulsory service from three years to one year. No regard for the social position or future prospects of recruits would lead the authorities controlling the sternly practical military system of Germany to make this regulation, unless they believed that educated men were able to learn their military duties so much quicker than ordinary conscripts. This feature has been adopted in France and Italy in connection with the rest of the Prussian system, and it is applied to the navy as well as to the army. In France a corps of professors is maintained to give gratuitous instruction in mathematics and navigation to the

members of the *Inscription maritime*, from which the navy is recruited. In Italy the military and naval services are doing much to remove the reproach of popular ignorance. The naval training system of England gives to each boy who passes into the service a better education than was received by lieutenants fifty years ago, and better than is offered at public expense to other children belonging to the same classes in society.

The United States is pre-eminently the country of popular education. In most of the States, gross ignorance in a young man would be attributed to foreign birth or parentage, grinding poverty, or worthless character and abilities. A certain standard of education is necessary to enable an American of the rising generation to maintain his self-respect. If this be wanting, fidelity and discipline can hardly be maintained. To enable the navy to draw its recruits from those who are essentially American, and to make them contented and respectable public servants, the importance of education must be recognized.

The average standard of cultivation attained by children of respectable families in attendance at the public schools should regulate the educational requirements of the naval training system. The best observers would hardly include anything more than ability to read and write intelligently, some skill in arithmetic, and some notions of geography, in the list of actual results obtained. These subjects could be taught to every boy of sound mind before he is drafted to a cruising vessel. No time need be wasted on commercial arithmetic or arbitrary grammatical rules, and no subjects should be taken up to be dropped without result, as they are in common schools.

The proposed standards must, however, be made higher for those who are to be advanced to expert and intelligent torpedo-men, gunners, or engine-room artificers. Selected boys who desire to qualify themselves for special work of this kind should be given opportunities to learn something more of mathematics, and to acquire some knowledge of elementary mechanics and mechanical drawing. They would then be able to acquire a practical knowledge of the instruments and machinery which they would be employed in using, much more quickly and intelligently than those who had received no such instruction. Advanced education of this kind is given to the men of special corps in other navies, and should not be neglected in our own.

The subject of education is sometimes turned over to the chaplain or other officers not engaged in the active technical work of the service,

as a matter of remote or trifling practical importance. To make it useful in regulating the naval training and improving the standard of discipline in our ships, active officers of the line and the engineer corps should supervise instruction in special branches, and should assist in conducting examinations and in selecting boys to receive special training. They would be usefully employed, and might hope to see large results from earnest work in this direction.

Only a few boys would be affected by the advanced courses suggested; the others would have received brief and elementary instruction only, and abundant time will be left for thorough practical training. It is believed that increased intelligence will result in an actual economy of time in carrying out practical exercises with thoroughness. The objection that enlisted men will be made wiser than their officers could hardly be made by any graduate of the Naval Academy, unless he had made up his mind to indulge himself in stupid indolence. Nor will discipline be impaired by education if a true standard for both be recognized.

To afford the greater part of our seamen of the future any share in the mental occupation which is necessary to insure health of mind and body to those deprived of the natural means of recreation by the confining and isolating conditions of service in a sea-going vessel, something more is needed. Among the popular amusements of the present day, miscellaneous reading holds, perhaps, the highest place. The universal prevalence of this taste is evident, and, in spite of many offensive publications, it has fewer drawbacks and dangers than most other amusements.

To the seaman who can read at all, reading offers more comfort than almost any substitute that can be proposed to fill his monotonous hours of leisure. The boys who are growing up in the service especially need inducements to avoid injurious vices and debasing idleness. To make our ships home-like and attractive, no cheaper or more effectual means can be devised than the supply of libraries of popular and interesting books to every vessel in commission. Those who glance over the newspapers and magazines every day are sometimes disposed to speak of books as being too dull for the present generation. But if the periodical literature of the day is out of reach, even the superficial and ignorant are willing to fall back on books. Newspapers are luxuries to a cruising vessel, but they can rarely be obtained when most needed. Professor Nordenskiöld, in his successful Arctic expedition, was able to satisfy the newspaper hunger of

his crew by serving out each morning a journal exactly one year old. But this would hardly satisfy young Americans.

The object of the suggestions which follow is a purely practical one. It includes the gratification of tastes which are almost universal among the young men who form the strength of our navy, and the supply of wants which are seriously felt. The supply of books suitable for the amusement of men condemned to the monotony ot sea-life is a disciplinary and hygienic measure. It supplies healthy occupation for the mind and promotes cheerfulness; it will tend to keep men contented on board ship, and, by enlarging the range of their interests, will give them something to do when on shore which may keep them away from the wretched haunts which deprive them of money, of health, and of character.

The efforts made by charitable and religious societies to supply our men-of-war with reading matter reflect credit upon their managers, but they are not calculated to supply the want most generally felt. Nor is it creditable to the service that it should continue to be a dependant upon such agencies for books which might be supplied by its own resources. These societies have other objects in view than the supply of amusing reading, and there are others who have stronger claims on their generosity than the crews of naval vessels. Where men are regularly paid and employed in large numbers and for long periods, nothing but organized action is needed to enable them to supply themselves with respectable libraries. The officers of our cruising vessels would share in the benefits of such action, and, from their position and education, should be the ones to undertake it. All who might assist in the work would be doing something for the good of the service, and those who expected to go to sea would be serving their own interests.

The problem would be vastly simplified by allowing the use of say $5000 for the purchase of books to inaugurate the system proposed. There would be neither extravagance nor injustice in such expenditure. It could be arranged so that it might be repaid in instalments, but the service would be benefited by a liberal foundation fund for the purchase of books. Dues could readily be collected to provide for the care, increase and renewal of books. If blank forms, specifying the character of the libraries to be issued and the terms upon which they were offered, were sent to each vessel going into commission, there would be little difficulty in securing subscribers to a fund proportionate to the number of books required by each vessel.

Libraries might be issued to officers' messes, to associations of members of the crew, or to the ship's company as a whole. In each case the signatures of the persons taking the books should be allowed to ensure the payment of the sums agreed upon. The paymaster could readily make the necessary collections, and other officers could carry on the correspondence and sign the necessary receipts. This would involve a little extra work, but it would be work in a field of the highest usefulness.

The task of purchasing books should be placed in the hands of an officer who could use the catalogues and other facilities of the library of the Navy Department. It might well be assigned to an officer acting under the direction of the Bureau of Navigation. Liberal tastes in literature, with a preference for simple and spirited modern writers, and a mild aversion for classical authors and standard works, would qualify any officer, not given to extravagance, and interested in the success of the plan, to undertake the arduous duty of purchasing libraries. Suggestions should be invited from every quarter, but the responsible officer should be at liberty to reject them when such action is necessary to ensure success. The average price of books of the class required should not exceed one dollar per volume, including cases and covers. Out of every hundred books, forty might be works of fiction, thirty voyages and travels, twenty works of history or general literature, and ten technical or scientific books. Experience would modify this list considerably, and special selections might be made for officers' reading. Due care should be taken to supply ships with books of travel and history relating to the stations to which they may be assigned. Each case of books should be furnished with price-lists in duplicate. Cases of nearly equal value should be exchangeable at any time. If the works selected were found attractive, there would be no trouble in collecting a percentage for their use large enough to put the system on a firm footing and to allow for expansion without external aid. No attempt should be made to connect this system with the small, and frequently antiquated, professional libraries supplied for the use of officers. The addition of new books to these libraries is a matter requiring constant attention, but it would not be desirable to attempt to combine the general supply of reading matter to the crew with these collections.

The details of this plan may be imperfect, but it is believed that they could be modified and made to work. The beneficial results of the introduction of books of an acceptable kind might not improbably

be perceptible in the reports of punishments, the record of desertions, and the returns of sick among our seamen. The system proposed is based upon national characteristics and conditions which will be felt more and more while the training system continues to be successful. If the work must be left to voluntary action, it would seem that the organization of the Naval Institute could be used to inaugurate its operations.

In fixing the character of the navy ration, the habits and circumstances of our people and the recent progress made in preparing and preserving food-products, should be studied with more care than the dietary scales of foreign services. Our merchant seamen in the days of our maritime prosperity, and our working population at all times, have lived better than corresponding classes in other countries. If our naval seamen are to be representative Americans, they must share in these advantages.

The ration now issued is liberal in quantity and it has been somewhat improved in quality and variety. Still salt beef is retained as a part of it, to be served out after it has lost the flavor or consistency of good meat. Dr. Kane's expedition found it a scurvy-breeder during the first winter, and came to consider it as a poison before they escaped from the ice. The improved methods of canning, drying and preserving foods seem to render change an easy matter. But each of the new articles requires to be carefully tested. The canned goods selected for one Arctic expedition spoiled in the railway transit. Those used in the Jeannette caused weakness and suffering to some of those engaged in the fearful and memorable retreat of her crew.

Every cruising vessel might have a board of officers, composed of the paymaster, surgeon, and one watch-officer, to conduct systematic tests of promising samples of food-products supplied for long voyages. Each article should be tested repeatedly by chemical analysis, by actual use, and by issue to messes among the crew. Full reports in regard to the purity, keeping qualities and general merits of each sample should be made. Comparisons of such reports should render it easy to make desirable changes in the ration of our ships' companies. Officers' messes would also be enabled to purchase their supplies with less risk. The work done by the boards proposed would be directly and practically useful to all who go to sea, and would promote the interests of the public service.

The work of exploring and surveying in remote parts of the world has always been considered suitable employment for naval vessels

and naval officers. Many of the scattered islands of the Pacific and some long stretches of coast of the American continent are very imperfectly known. Extensive surveys are required to render navigation safe, and to promote commerce and civilization. The exploration of the depths of the ocean and the investigation of ocean currents also promise results of commercial importance. All of this work must be done at the expense of the great maritime nations, and by men-of-war under the control of educated naval officers. The activity and vigilance necessary to ensure the safe handling of ships in unknown waters tend to develop the highest nautical qualities among the responsible officers thus employed. No better training for the seaman and the navigator can be found than that afforded during an extended voyage of exploration.

Besides the commercial and nautical value of the results attained by successful work in this field, the advancement of science should justify the equipment of exploring expeditions. Facts that were merely curious fifty years ago are now highly significant and important to scientific workers. The combination and interpretation of the records and observations of intelligent navigators will continue to furnish means for the organization of natural science. Every branch of natural history has its claims upon the attention of explorers and surveyors. The report of the Wilkes exploring expedition remains a monument to the wise liberality of the government in a past generation. The constant references to that report in the works of such writers as Darwin and Herbert Spencer show its value and do much to increase the respect entertained for our government and its naval service. Much may also be done to complete our national collections and to make them more useful in promoting research and education.

If naval officers trained for the work of surveying, observing, and collecting, take part in navigating and working vessels thus employed, there will be large gains in efficiency and economy. The large scientific staff required for the Wilkes expedition deterred several officers from accepting the commands offered to them, and delayed the departure of the vessels. The limited accommodations of a surveying vessel, combined with other considerations, render the presence of a large number of persons not connected with her regular work inconvenient and undesirable. Agassiz and other eminent men of science have testified to the cheerful and efficient assistance rendered by naval officers. It has been shown in a preceding chapter that naval

officers can be trained to render still more intelligent and valuable aid by the methods of instruction now open to some of them. While men of scientific authority should be invited to take part in such expeditions, as well as in framing plans for regulating their operations, it would seem that most of the practical work might be done by trained officers of special acquirements who would be able to do their share of the regular duties of a man-of-war.

There is one field of exploration from which purely naval expeditions should be excluded for the future. The vast ice-field which surrounds the North Pole should never again be entered by the keel of any man-of-war or exploring vessel. Arctic explorations have produced some of the most fascinating literature of modern times. Its records are full of terribly impressive incidents, of which the latest and most tragic has stirred the feelings of every officer in the United States. But after a generation of heroic explorers have risked or sacrificed their lives in this work, we are compelled to ask what results have been accomplished, or at least what methods of advance have been made practicable for future expeditions? The records show that ships are helpless and useless in the ice, and that they must keep close to the coast in order to liberate themselves at all. The system of establishing stations on land is the only one which promises any results of scientific or practical value. If young and ardent naval officers wish to join in the work of these stations, and are willing to learn to be thorough observers and recorders of all the data which it is the main object to collect, their services will be found useful and acceptable to expeditions organized on this plan. Their training as seamen and navigators would increase their adaptability for the work, but those who are seamen and navigators only have no business in the Arctic ocean where ships cannot be made to assist in the work.

The habitable and fruitful portion of the earth is capable of furnishing solutions for scientific problems of far greater importance than those dependent upon the discovery of the pole. Ethnology and natural history, the distribution of animal and vegetable life, all present facts capable of comparison and interpretation. Darwin was led to adopt the views which have revolutionized natural science and made it capable of explaining social as well as physical phenomena by what he observed in his voyage in the Beagle, and the journals of intelligent travellers and navigators are constantly made use of in completing and applying the ideas and methods thus inaugurated.

The opportunities of a survey carried on by men-of-war would also tend to the extension of commercial relations and of national influence. If we send only missionaries and whalers to seas where other nations send men-of-war and merchant steamers, we can hardly expect savages to respect the power of the nation or the rights of its citizens. Moreover, the discipline of any efficient man-of-war and the armament which she carries enable her commander to insist upon proper treatment for his countrymen, and to impress his views of morality and propriety upon men not easily influenced by the arguments or persuasions of those destitute of visible strength or support. The islands of the Pacific, the coasts of the American continent, and the bed of the ocean will furnish employment for all the vessels and officers that can be spared for such purposes for many years to come.

The Hydrographic Office only needs larger resources to enable it to regulate the operation of surveying expeditions and to publish to the world the results achieved. Its methods and organization would admit of the expansion required, and those officers who were familiar with its duties would be valuable assistants in carrying on the work of a surveying vessel. In this field, and in its meteorological department, the capabilities of the Hydrographic Office should be recognized and developed. No part of the work of collecting meteorological data and publishing them to navigators in the form of wind, weather, and current charts, should be allowed to fall into the hands of any organization established for other purposes, or imperfectly prepared to accomplish practical results.

The Naval Observatory has also a claim for means to enable it to extend the benefits of its time-signals to every port or anchorage frequented by sea-going vessels on our coast. This institution is connected with the navy for practical purposes, and it should be enabled to render liberal aid to navigators in accordance with the methods suggested by the practical experience of naval officers. It should also be used to promote training in the use of astronomical instruments, a number of naval officers to take part in observing celestial phenomena or in conducting accurate surveys. While it may not be possible or desirable to make every naval officer a practical astronomer, it is necessary that the service should keep up a regular succession of trained observers capable of doing good work upon occasion. If training on this system is continued, and if officers are employed in transmitting standard time and correcting the navigating instruments, the work of the Naval Observatory will be-

come one of the most important fields of usefulness open to naval officers.

The system of requiring reports and studies from officers of certain grades will tend to enlarge the work of the Office of Intelligence, which has recently been organized in the Navy Department. The considerable amount of valuable information and original research which this system would produce should be made available and useful to individual students and to other organizations. The publication of bulletins of the work of this office would also tend to the advancement of professional knowledge. The work of this office will require special capacities from those engaged in it, and it will also afford special experience tending to fit them for duties of great importance.

The Naval Academy will offer inducements to many who may desire to avail themselves of opportunities for taking advanced or experimental courses of study. Many of its resources are not made the most of by the cadets during their hurried course. The presence of advanced students might be made useful to those taking the regular course of studies. Any movement for the extended application of scientific methods to naval requirements will tend to connect itself with the Naval Academy. Officers who have made themselves specialists should be employed in revising text-books and manuals of technical subjects, in order to keep them in harmony with the results of progress. The lessons of every recent naval war should be studied in connection with each of the branches taught at the Naval Academy, and pamphlets or lectures should be used to interest the cadets of the higher classes in these subjects. The professional course at this institution should certainly include an analysis of the methods employed and the results achieved during the last great war in which our navy bore a part.

V.

A summary of the contents of the preceding pages may fitly introduce the concluding remarks of this essay. The reasons for extending the sphere of usefulness of naval officers and the general considerations regulating their employment in the proposed fields were first presented. The principle upon which the succeeding recommendations are based is that of making use of special faculties in doing special work. For the development and cultivation of these faculties a system of advanced education and training is proposed. The opportunities for the useful employment of naval officers in branches

of the public service which are not at present under the control of the Navy Department are next presented. Special importance is assigned to the supervision of our maritime industries and the care and preservation of our harbors. Methods of extending the usefulness of naval officers while engaged in the performance of strictly naval duties are next treated at some length. The proposal to require reports and studies from officers of nearly all grades is advocated as a means of training for the higher professional duties as well as for collecting valuable information. Methods for increasing the intelligence and promoting the comfort of the seamen of the navy by encouraging sound elementary education, by supplying attractive libraries to men-of-war, and by improving the navy ration, are next presented. Finally, the claims of various organizations employing naval officers in useful scientific work are presented with a view to their recognition and the development of their resources.

The recommendations made with the purpose of using and cultivating special abilities may be found defective in detail without impairing the value of the principle upon which they are based. Many of them are mere suggestions, and the definite form in which others are presented has not been adopted from any disposition to cut off discussion or amendment. It has seemed best to offer something definite enough to admit of criticism and revision. This paper can have no practical value unless some of its suggestions provoke discussion and arouse interest among those to whom it relates.

The effect of the system proposed upon the regular naval employment of naval officers may require some explanation. Duty in those branches of the public service which enable officers to take an active part in the management of sea-going vessels should be recognized as sea service, and alternated with shore duty of a strictly naval character. On the other hand, shore duty of a kind extraneous to the naval service should be assigned only to those who have completed tours of duty in cruising men-of-war. The essential nature of the employment in each case should be considered; no officer should be withdrawn from active professional work for more than three years at any time. All courses of study would, of course, be taken up during the periods now spent on shore duty of an inactive kind or on waiting-orders. Those who had completed such courses should be assigned to employments favorable to the practical application of their newly-acquired knowledge.

The system of reports and studies to be sent in at regular intervals would occupy a considerable amount of the spare time of those who

endeavored to accomplish results of value and importance. As the reports of officers of enlarged experience and mature character would generally be the most valuable, they should be given time and opportunity for collecting the information and doing the work required. To allow for this while on sea service, junior officers should be required to perform a certain portion of the routine duties of the ship. Thus midshipmen and ensigns may be learning the duties of watch and division officers in a practical and responsible manner, while officers who have been carrying on these duties for many years are fitting themselves for higher commands and wider fields of usefulness.

It may be objected that employment in some of the branches of the public service which have been proposed would tend to cause the resignation of some of them whose tastes and abilities might lead them to other fields of usefulness than those of the naval service. The occasional resignation of such officers would hardly injure the service; on the contrary, it would help to afford much-needed opportunities for promotion to young officers who might otherwise be compelled to wait for a weary period. Nor would those who voluntarily left the navy to do special work in other branches of the public service, be lost to the country or deprived of all interest in the service for which they had been educated.

It may be thought that rewards of some kind will be necessary to induce any considerable number of officers to prepare themselves for extended fields of usefulness. No such necessity will exist if willing and capable officers offer themselves whenever there is a demand for their services; and there is every reason to believe that there will be an abundant supply. The English system of giving increased pay to those who qualify themselves to serve as gunnery officers, interpreters, etc., seems to establish too low a standard for the majority, and to be inapplicable to our service. The promotion, in advance of their regular turns, of those who distinguish themselves in these fields of employment, or in any other manner, might seem desirable if the practical difficulties of the plan were less formidable. To base selection upon explicit reasons or fixed standards would tend to discourage the cultivation of special talents and the acquirement of varied knowledge. Competition of any kind introduces uniformity, if injustice is to be avoided. Practical equality in opportunities is unattainable in the naval service, and the irritation of protracted competition is unfavorable to the discipline of the service and to the sound

mental progress of officers of mature years. Selection based upon principles and methods which cannot be announced beforehand involves still more injustice and demoralization. It would bring into the naval system the dangerous habit of relying upon favor or influence for advancement, which has been found inconsistent with soundness and efficiency in the civil service. Moreover, selections made in time of peace, by whatever methods they may be regulated, must be largely independent of the military or fighting qualities of those preferred.

There is no lack of inducements for earnest and faithful work in any of the directions which have been pointed out. Every officer of active mind and definite purpose will be glad to be assigned to duty in any congenial employment where his responsibilities and opportunities for improvement will be increased. Those who hope to qualify themselves for command and for war service will be the first to seek posts of responsibility and activity from which they might be debarred by their rank were they strictly confined to naval routine. The weakness of our naval material renders such preparation a matter of the first importance to those who must develop and transform our fighting fleets, and who may be compelled to accept the censure due to those who have not provided for the necessary improvements of our material.

Nor can training for command be postponed by officers now in the junior grades until they shall have reached the period of actual assignment to its duties. Age will render it hard for them to learn promptly and thoroughly what they ought to know.

Other and higher considerations invite naval officers to seek enlarged opportunities for serving their country. The nation, which has a right to all our energies, has passed beyond the type of a militant society and has become a great industrial society. It is organized for peace rather than for war. Its defensive powers depend upon its wealth and its industrial and scientific progress. It is the duty of those who may at any time be called upon to use these resources for warlike purposes to study them in detail, and, as far as possible, to connect themselves with those industries and interests upon which the navy must depend for its growth and transformation in time of war.

Realizing, as Americans, that we belong to the nation of the future, and believing that the navy will continue to be a factor and an element in our national progress, we should blend our personal ambitions in

efforts for the future of the service. Tradition and example are very powerful in controlling its progress, and we owe much to those who have maintained the traditions of professional skill and intellectual activity which have characterized our service at every period of its history of glorious achievements. Many who have contributed to these results have never reached high rank or personal distinction, and their merits may have failed to secure recognition or reward. The service at the present day offers few large emoluments or public honors to the rising generation of its officers. It may, however, give them opportunities for applying their faculties for the benefit of the country and the navy of the future. Those who understand and accept such responsibilities may not escape from obscurity, but they will work to connect the service with the progress of the nation and of the race. They will devote themselves to enlarging their capacities for usefulness and to setting a good example to those who may come after them—*Pour encourager les autres.*

NAVAL INSTITUTE, ANNAPOLIS, MD.

APRIL, 1883.

HOW MAY THE SPHERE OF USEFULNESS OF NAVAL OFFICERS BE EXTENDED IN TIME OF PEACE WITH ADVANTAGE TO THE COUNTRY AND THE NAVAL SERVICE?

BY COMMANDER N. H. FARQUHAR, U. S. N.

"*Semper Paratus.*"

In time of peace, prepare for war, is the paramount duty of a nation; and particularly is it so of the naval part of it; and in no way can a naval officer serve his country and the service so well as to keep his mind and body in readiness for the emergency of war.

Were I to give advice to an officer on this subject I would say, read and study. Idleness in a naval officer soon makes him rusty and of little value to his country or the service. Commodore Roe, in his admirable work, says: "The naval officer is always at school. The very routine of his profession changes day by day. Progress and invention changing, keep him ever learning new things, solving new problems. To keep pace with the progress of his profession he must be a scholar as well as a laborer."

Some time since, when the subject of naval education was under discussion before the Royal United Service Institution, in England, Admiral Ryder, an officer of high attainments in that navy, remarked: "It has been truthfully said that it is almost impossible to name any scientific acquirement which a naval officer may not find professionally useful at some period or other in his career, so multifarious are the duties which fall within the sphere of a naval officer's action."

Another officer: "We all must agree that the more scientific an officer is, the better officer he is."

Another said: "Our naval officers must be educated in all the subjects that come before them, not only scientific, but those that relate to the changes in our material. Having under them educated and trained seamen whom they must command by their knowledge of their profession in its entirety, which constitutes power, there would be less trouble on board ship, discipline would be better kept up, and our officers would be in a position to deal with any subject that came before them."

Commodore Goodenough, who strove so hard and untiringly for a higher education in the English navy, and whose sublime and heroic death won the admiration of the world, said: "I have been told that it is not desirable to make the navy a scientific service. Science indeed! we are far from that. We are safe enough from any charge of that sort. I only wish for such an education and training as shall enable an officer to understand a few elements of the laws by which their ships float and move and are guided. Such an education would excuse them from asking the impossible in a ship, while it prepares them to comprehend the simple phenomena and acts of nature. I believe I may boldly say that we have scarcely a man in our naval history, distinguished as a naval commander in action, who has not also been distinguished in some other pursuit, professional and otherwise, practical or scientific. Nothing you can learn will come amiss to you in your profession. Nothing you can learn will be useless to you. If you wish to serve your country as a commander of any force, great or small, you must nourish yourself with study. Opportunities come in vain to men who are not prepared."

"The thousands of naval officers whose race is gone, or going by, have sunk and are now sinking to repose with each his little meed of success or fame apportioned or appreciated according to his opportunities. But the State in the past time is the same State still, and who shall say what may not have been lost irrevocably through the very want of study? What discoveries in science, what combinations of philosophical reasoning, what deathblows to one's enemy's resources may not have been missed solely because our officers have not travelled out of the usual routine of professional duties!

"The opportunities enjoyed by them of original observation are incomparably greater to those possessed by any other body of men; their leisure is even a burden to themselves. And yet how few of them have assisted the progress of science by any great original discovery."

Firstly. Study the means of increasing the fighting power, and would suggest the following subjects:

INCREASE OF FIGHTING POWER.

Tactics of Battle,
Improvement of Men,
Improvement of Ships,
Improvement of Guns,
Improvement of Projectiles,
Improvement of Torpedoes.

Secondly. HYDROGRAPHIC INFORMATION.

Geography,
Currents of air and water.

Thirdly. HISTORY.

Naval History,
Natural History.

Fourthly. LANGUAGES.

Fifthly. PHYSICS.

Natural Philosophy,
Chemistry.

It would be better for an officer to confine himself to one or two subjects, and to follow them up; and since the various ramifications of science are interwoven with, and to a great extent depend upon, each other, he could not fail in gaining a thorough knowledge of one to acquire a certain insight into others.

Tactics of Battle. With the many changes in the construction of vessels, their motive power, their armament and means of defense, as many changes will be necessary in fighting them. Indeed, the circumstances of different naval engagements are rarely the same; the arrangements and manœuvres for one would not be applicable for another. In all battles in which fleets were engaged the combinations were different. This is strikingly illustrated in the battles of Trafalgar and Aboukir. In our late war, at Port Royal, where the fleet underway delivering their fire in succession, being in itself a movable target. At Mobile, when to lessen the chances of being disabled in passing the forts, the vessels were lashed in pairs, and thus if one was disabled the other would carry her to the front.

At Fort Fisher, where an immense fortification had to be silenced, the vessels were arranged so as to bring the most effective to bear full on the forts, with the others to fill up the gaps, and in a short time not a gun could reply. The Kearsarge and Alabama manœuvred in a circle, which was unprecedented. Fifty years ago, to have fought end on would have been madness and the result destructive from the raking fire. To-day, with modern ironclads and rams, to engage end on would be the proper thing to do. It should be borne in mind that successful naval commanders have originated their plans of attack and action, not on the spur of the moment, but have studied them out beforehand.

We can discuss them afterwards and see how they might have been frustrated; but how much better to have thought and studied beforehand, and been ready.

To Improve the Ship's Company. To do this does not simply mean to exercise and drill them, but to make thinking men of them; to intelligently study the means of retaining their health and increase their powers of endurance.

With the improvements in ships and guns the seaman must advance. Anybody could train and fire an old-fashioned broadside gun; but with breechloaders of delicate mechanism, and gun-carriages worked by steam, the recoil controlled by intricate mechanical contrivances, where one shot equals in weight a broadside of a sailing sloop-of-war, and in destructive power is beyond comparison—all require a superior intelligence and training widely different from that of a few years ago. The officer to give this training must keep well in advance himself.

In a conversation with the late Admiral Tegethoff, the hero of Lissa, he informed me that he owed his success to the superior training and discipline of his men, as his vessels were inferior to those of the Italians

Our successes in the war of 1812 were largely due to our superior seamen. The best sailors in the world not ably commanded would never gain a victory.

Improve Ships. Increase the fighting qualities of those we have and plan new ones. In one short year the monitor-type of vessel made a revolution in ships for war purposes. Had we possessed a fleet of these vessels when the late civil war broke out a few months would have ended it. The change then made from wood to iron in construction was only the beginning of the changes in form and ma-

terial which to-day gives us steel vessels with compound armor and a high speed.

The change of the Merrimac, in a few months, under adverse circumstances, from what was considered the finest steam frigate in the world, to an ironclad that was more than a match for several of her former class, was wonderful, and is an evidence of what can be done. We might be called upon to do the like should an enemy threaten our shores.

Guns and Torpedoes. It is still a mooted point which of the three, ships, guns or torpedoes, are the most effective. That the limit in weight of guns that can be carried on board ship with safety has been reached seems to be settled. But the explosive agents and projectiles that can best be used are yet to be determined. The torpedo is yet a matter of experiment, and who can tell how important a part it will take in future actions? How to construct them, how to use them effectively, are problems to be solved, and worthy of our earnest thought and study.

The immense charges of powder, on account of their bulk, are inconvenient to handle, and the space required for stowage makes it necessary to seek for other explosive agents, both for guns and torpedoes.

To find such an agent is no easy matter ; but a study of chemistry might lead to such a discovery. An officer then could render no better service to his profession and his country than to study in this direction, as the result of study might give his country a very decided advantage.

Hydrographic Information. The necessity of which is so apparent as to need no argument. I would have it taken in its broadest sense, including the tides, currents of the ocean, as well as geography.

History. History is said to repeat itself. The rise and fall of a nation is an interesting as well as a necessary study for a naval officer. Did the rise result from warlike proclivities ? If so, were they natural, or can they be cultivated ? If cultivated, what were the means, and can such means be used now? Then their decline and fall. What contributed to it? What have navies had to do with either? And would the possession of an efficient navy have changed the result ?

Almost every memorable epoch in the history of nations has been connected more or less intimately with a battle on the sea. For example, the battle of Lepanto checked the spread of Mahometism and sealed the fate of the Turkish Empire, gave courage to the

Christians, and restored their religion to a large part of Europe. Again, had England had no navy to baffle the Spanish Armada, who can say what the condition of Europe would be to-day?

Naval history cannot be too closely studied, and we must gather from it that naval heroes were self-made, and that no power behind a throne can insure a naval victory.

The war of 1812, on account of our victories on the seas, gave a prestige to the United States which they have never lost.

We should study history to learn the character of the various peoples; their fighting powers and qualities; their resources, agricultural and mineral; their armies and navies; and last, but not least, whether there may be certain portions of the countries which are bound to the main portion by the strong arm of might rather than by common consent. The condition of the merchant marine, in vessels and men, as this is the chief source of supply to a navy in time of war.

A knowledge of the agricultural resources is very important, because when these are deficient a rigid blockade would have to be maintained. Besides, the necessity of knowing the ports whence a ship's provisions can be had; and as States change from agricultural to manufacturing, or *vice versa*, we should keep ourselves continually posted. So also the mineral productions should be known, not only on account of the material for making cannon, &c., but coal to supply the navy. A modern ironclad without coal is powerless. New coal-fields are continually being discovered, and to know *where* to get this important article is our duty.

The condition of their armies and navies: Did we have a powerful neighbor on this continent the necessity would be more apparent.

How unfortunate it would be for a commander to engage in a battle with a fleet or vessel of which he knew nothing, neither the strong nor vulnerable points, and yet this might happen if the commander did not read and study of the various types of vessels.

So with the army. While the navy is not expected to engage an army, still it can create a diversion by attacking at some remote point, rendering necessary a division of the enemy's army. Had the French navy done this during their recent war with Germany the result might have been different. Its inactivity, it is believed, enabled the Germans to concentrate their forces and thus overwhelm their enemy.

Modern Languages. It requires no argument to show how the sphere of usefulness of a naval officer can be extended by a knowledge and study of modern languages. It is only necessary to call to mind how the services of naval officers who are linguists are sought after in times of peace as well as of war.

I have so far mapped out what an officer may accomplish with the facilities they all have, and with the education the government has given them they ought to be able to pursue.

There are other subjects, Natural History, Natural Philosophy and Physics, which require aid to commence, but once fairly started can be readily followed.

In the navy, as a rule, the naturalist has a very wide field, as well as a very interesting one. Nearly every cruise extends over many degrees of latitude, thus ever varying the climate, and consequently the productions, vegetation, winds, weather and the many phenomena so engaging to a naturalist.

Professor Munroe remarks, in a letter addressed to the Honorable Secretary of the Navy: "While in the ordinary practice of their profession it might serve only as an improving pastime, yet when sent, as they often are, on expeditions to unfrequented lands, it becomes very useful; and when engaged in the work of the Coast Survey and the Fish Commission, and surveys of the ocean bottom, such knowledge is essential to complete efficiency."

How useful to the service and to the country would it be did officers possess such a knowledge of some branch of natural history as would enable them to study intelligently the land or water they might explore.

Facilities are now given at the National Museum in Washington to study this interesting subject in some of its branches, and it is to be hoped that future expeditions will have naval officers as naturalists.

The navy has been called upon in the past few years to explore the isthmus between North and South America, and to locate routes for canals. How essential to reliable reports was a knowledge of natural history and natural philosophy.

Lastly, *Physics.* The mere mention of the subjects under this head is enough.

Astronomy,	Chemistry,
Heat,	Light,
Magnetism,	Electricity.

Let an officer pursue any one of them and the result will show the utility.

Steam generated from water by heat from coal is the motive power of to-day, but it must be developed more economically, either by using coal or other fuel, or it will be erelong replaced by electricity as a motor.

These subjects then present another opportunity for a naval officer to be useful to his country and the service in time of peace.

The maintenance of a navy is largely increased by the consumption of coal. An officer inventing means of reducing this expenditure will most certainly have extended his sphere of usefulness to the country and the service.

"An officer who has improved his time by study would not only have effective claims to selection for the conduct of almost any special service, but would be qualified to make a *special service* of the most ordinary routine by the capacity he would have of blending scientific inquiries with every department of duty.

"Should any novel emergency of either attack or defense arise in a squadron in which he might be serving, with what advantages would he enter into council; with what deference would his opinions be listened to. In whatever corner of the world their lot of service might be cast they seize the passing or permanent phenomena of nature with the understanding of men acquainted with whatever is known on the particular subject, and ready to notice and to reason on the peculiar variety, should any occur. Should they visit a country for the first time, their account would be complete in all its parts, its capacities, natural and political, would be appreciated with judgment, and the manners, customs, institutions, civil and religious, of its inhabitants would be reported without exaggeration, and connected probably with the history of the species at large by some minute analogy of practice or community of belief, the observation of which might have escaped a less gifted traveller."

NAVAL INSTITUTE, ANNAPOLIS, MD.

April, 1883.

HOW MAY THE SPHERE OF USEFULNESS OF NAVAL OFFICERS BE EXTENDED IN TIME OF PEACE WITH ADVANTAGE TO THE COUNTRY AND THE NAVAL SERVICE?

By Captain A. P. Cooke, U. S. N.

"*Cuilibet in arte suâ credendum est.*"

There is no question about the sphere of usefulness of naval officers in time of war. But, owing to a prolonged peace, the necessity even of maintaining such officers is sometimes questioned. In order to keep its position among the nations of the earth, every country is obliged to have a war establishment of some kind; depending upon its location and surroundings, upon its obligations and duties. When we survey the vast extent of our own land, intersected as it is by great navigable rivers, surrounded by two oceans, the gulf and the great lakes, with an enormous coast-line studded with commodious harbors, and when we reflect upon our immense undeveloped capabilities, upon our extensive commerce, which compels us to trade across the broadest oceans with the most distant lands, we may justly aspire to commercial supremacy and to hold a position in the front rank of nations.

Such a position cannot be successfully maintained by us without an efficient navy. A naval force is necessary for the protection of our coasts and commerce, of our citizens and their property on the ocean and in distant lands. It is necessary to the preservation of our peace and the efficiency of our negotiations with foreign nations, to the advancement of our commercial interests, the maintenance of our appropriate position among nations, and the prompt vindication of our rights and the honor of our country. All these requirements for

a navy are even necessary during seasons of profound peace, but as the history of the past does not warrant us in supposing that peace is to be our perpetual possession, we also need a navy to fight the battles of our country in time of war.

The necessity for a navy being conceded, its efficiency should be such as to give it a reasonable hope of success, when opposed by those it may have occasion to encounter. Of all the means which may be employed to accomplish this end, none can be more important than that of maintaining a competent and efficient corps of officers; without which the finest ships and the most effective guns will be of no avail. But when the ships are suffered to deteriorate and the guns become obsolete and the whole system of naval defense is neglected, it must have a chilling and injurious effect upon the officers. How can they keep up their enthusiasm and their ambition and their desire to fit themselves for their high calling, when the tools they must use are old and worn out and worthless? If war unhappily comes, the public will probably trust in Providence to point the way to quickly improvised methods of defense, but the officers cannot be improvised; they must be kept ready in case of need, unless we utterly neglect our obligations and wilfully jeopardize the life of the nation. And those who cannot serve must of necessity stand and wait. The question is, how may their sphere of usefulness be extended?

Naval officers are selected in their youth from all parts of the country, and carefully educated by the government for its service. They are brought in contact and in friendly emulation with youth from all parts of our great domain, and soon lose all local prejudice and sectional feeling in a broad sentiment of patriotism and love of country; the fittest only survive the careful culling continually going on, and those who receive certificates of graduation are efficient, capable and ambitious. They have a high sense of honor and feeling of *esprit de corps*, and the country may well repose special trust and confidence in their patriotism, valor, fidelity, and abilities. It is a great mistake to discharge such men after so much care and expense have been lavished by the government on their training. All officers of the navy, except those of the medical corps and chaplains, should be appointed from graduates of Annapolis, and instead of sending the surplus graduates to their homes, they might go into the Revenue Marine, or even into the consular service of the country. What special use can those who are relegated to their homes ever be to the

government in return for the careful training they have received at its hands? Yet the government has need of just such capable material in various branches of the public service.

In order to show how the sphere of usefulness of naval officers may be extended, it will perhaps be well first to consider briefly the present limits of that sphere. Our naval officers are employed at present in maintaining and using the limited naval establishment provided by the country. They are occupied on shore at the various naval stations, in guarding and protecting the public stores and property. In designing, building, rebuilding, repairing and fitting out the vessels allotted for service. In the manufacture of engines, boilers, rope, anchors, cables, rigging, sails, etc. In preparing the arms, ammunition and other public stores for the use of the fleet. In the preliminary training and education of both officers and men. In the preparation of charts, almanacs, sailing-directions and other aids to navigation. In the care of chronometers, compasses and other nautical instruments. In the supervision of lights, beacons, buoys and all other guides for the safe piloting of vessels on our extensive coasts, lakes and navigable rivers. In the development of signals, torpedoes, explosive agents and a new armament for our ships. In service on courts-martial, boards of inquiry, inspection and examination, and in the different bureaus of the Navy department.

All these important duties require the continual service of officers on shore, and it is wrong to suppose that naval officers are only needed for service afloat, and should be off duty when ashore. There is as much, and quite as important, duty involved in the preparation of ships for service and in keeping up the necessary establishment on shore, as is required for their use afloat. No one can be so well fitted for this duty as naval officers, who have to use the implements provided, and are thoroughly conversant with the needs of the service and have its best interests at heart. Moreover, all such service affords an important training and keeps the officers abreast with the improvements and changes continually going on, besides giving the government the use of the most intelligent, faithful and devoted servants it could find for the purpose.

Naval officers are employed afloat in using the force furnished. First in importance comes duty in regularly commissioned cruisers armed for service, where the routine of a man-of-war is strictly enforced, and where is to be found a school of practice for both officers and men. The ship, her armament and equipment, are tested

and proved, and her people drilled and trained; they are made familiar with the vicissitudes of service afloat, and capable of battling with the elements and the enemy. Nothing but actual service afloat will accomplish this, and if the facilities are not afforded, the *personnel* cannot be kept efficient. Ships must be had for this purpose, and the officers familiarized with their management. They must all have a fair proportion of experience in regular cruisers, during service in each grade, as the only means of fitting them for all the duties of their office. They also perform duty afloat in ironclads, equipped for harbor and coast defense, in practice-ships and training-vessels for the education of apprentices and cadets, and in surveying vessels, both on our own coasts and abroad.

Probably the most effectual way of increasing the sphere of usefulness of naval officers in time of peace, would be to prepare for the time of war, which must be inevitable, by building up and maintaining a naval establishment commensurate with the needs of the nation; thereby furnishing the legitimate and varied occupation so essential to the efficiency of the naval service. The time of peace would seem to be the appropriate season to design and test whatever may be calculated to make our navy formidable and effective in time of war. Remarkable changes are taking place in naval matters continually, and there is no reason to suppose that we have yet reached perfection in these matters, or that we have attained the ships and armaments best fitted for permanent adoption. If a navy is ever to be used in earnest, the wisdom of keeping it continually in an efficient state is undoubted. Unfortunately we have from our earliest history, in the moment of danger, temporarily increased our naval power at enormous expense, and, as soon as the danger was passed, we have always relapsed into our usual condition of weakness and inefficiency. This course has cost the country many times more millions of dollars than were necessary to have made and maintained a most powerful navy. But our wonderful recuperative ability makes us soon forget our great losses, caused by our want of foresight and neglect to avoid the waste of precipitation.

If a sufficient naval establishment is not available for the employment of all the officers, there are many congenial avenues where their peculiar training may be profitably utilized in the service of the government, and where their faculties will neither rust nor their ideas stagnate. Their special training and experience particularly fit them for the performance of duties in connection with ships and shipping,

and all matters where the knowledge of a marine expert is needed. Whenever officers of the national government are required in the performance of duties connected with the merchant marine, naval officers would be the most efficient, economical and reliable persons to employ; and retired officers of the navy might many times be profitably used and do efficient service for the government in these civil occupations.

There are several branches of the public service where vessels and seamen are employed, other than under the control of the navy. Considering the great advantages possessed by the navy, for the training of officers and men, and for building, repairing and fitting-out vessels, and furnishing their necessary stores and supplies, it would seem to be in the direction of public economy and efficiency to gather all these together under one general management. The large plant and immense amount of stores and equipment necessary to supply all these various interests could certainly be cared for and provided more economically and efficiently in that way. This would very extensively enlarge the sphere of usefulness of navy officers, and be of great advantage to the country, by placing the Revenue Marine with its Life-Saving Service, the Coast Survey and Light-House Establishment, under the care of the Navy Department. Then the many navy-yards of the country would offer accommodations for all their stores and fittings, furnish and equip their vessels and supply their wants. Great economy should certainly result. It would not be necessary to keep up so many separate establishments, and the whole business could be managed under one organization.

The Light-House Establishment affords a striking instance of how the sphere of usefulness of naval officers may be extended with advantage to the country and the naval service. Before the organization of the present Light-House Board the light-houses were in charge of the Revenue Marine Bureau, and revenue-cutters were employed on light-house duty. In 1838 a board of navy officers was created to examine into the light-house system, and on the report of that commission the coasts were divided into districts and a naval officer assigned to each. These officers were required to report, among other things, as to the plan, site and need of each proposed light-house, and did their duty so thoroughly that Congress, for the first time, had a full and clear knowledge of the real needs of commerce, and was enabled to provide for and meet its immediate necessities. The wants of shipping, however, soon outgrew these new

plans, and a mixed commission of army and navy officers was raised to inquire into the Light-House Establishment, and report a programme to guide legislation in extending and improving the system. Their labors resulted in the creation of the present Light-House Board, composed chiefly of navy officers and officers of the corps of engineers of the army. This board was authorized to discharge all the administrative duties relating to the construction, illumination, inspection and superintendence of light-houses, light-vessels, beacons, buoys, sea-marks and their appendages; procuring supplies and materials, and keeping all the property in good repair. A naval officer was appointed as inspector of each light-house district, who, under the special direction of the Naval Secretary of the Board, was charged with the maintenance of light-houses and lights, with the discipline of the keepers, and the location and care of beacons, buoys and all other sea-marks. A vessel was furnished each inspector to visit and supply the different stations, and they are always busy carrying supplies to the light-houses and caring for the beacons, buoys and other aids to navigation along our coasts.

It is a fortunate thing for the navy that this business of light-house inspection was placed in the hands of naval officers, who have performed the duty faithfully and well; expending judiciously and with clean hands the large appropriations devoted to that service. The navy can justly point with great pride to the work it does in the light-house service, as indicating what it can accomplish when employed in the civil service. The Light-House Establishment is for the benefit of shipping, and yet, singularly enough, it is not under the control of that department of the government which should have exclusive management of all nautical matters. The officers have to be transferred temporarily from the navy to the control of the Treasury, while the vessels belong to the Treasury. The vessels are not always appropriate for the service. They should be staunch sea-going propellers, of sufficient size to endure the bad weather they must frequently encounter, and with engines of sufficient power to brave an ordinary head sea. They would afford excellent commands for young navy officers, and give them valuable opportunities for gaining practical experience afloat, and becoming familiar with the handling of steamers and the approaches to our harbors. When these vessels come in for stores and repairs, they have no rights at our navy-yards, though belonging to the same owners.

The Revenue Marine Service has in the popular estimation an indefinite relation to the navy, and it would be an advantage to both

services if that relation were fixed and definite; the former being a regular coast-guard service and naval reserve. There is no better field for the extension of the sphere of usefulness of naval officers in time of peace than this. The Revenue Marine has over thirty vessels, two hundred officers and seven hundred men. The cutters are handy armed steamers of light draft, frequenting all the waters along our extensive coast-line, for the protection of the revenue, and to assist vessels in distress. Vacancies in the service are filled by the appointment of cadets, who are required to serve a satisfactory probationary term of two years, and pass the necessary examination. The scope of the examination covers only the ordinary English branches. The cadets are first sent on a practice-cruise at sea, in a revenue-cutter detailed for the purpose, and are carefully trained in practical navigation and seamanship. During the winter they are instructed in mathematics and such other studies as will best fit them for the proper performance of their duties as officers. A second cruise at sea is followed by another winter of study and training on shipboard; when after examination they are, if found qualified, appointed third lieutenants in the service. The surplus graduates of Annapolis would make infinitely superior material for appointment as officers in the Revenue Marine, besides saving to the government all the expense of this preliminary training, and keeping on hand an efficient body of officers always available for active service in time of war. This service would afford a fine practical field of usefulness and a school of practice for young officers, where they might become familiar with the revenue laws of our country and our commercial interests; become acquainted with our coasts and harbors, and gain valuable experience in handling steamers. Under the present organization, the vessels of this service are not entitled to the privileges of our extensive navy-yards and never enjoy them. If they want to repair or refit they go elsewhere; and if they require to be docked it is done by private parties; when, perhaps, the government dock is adjacent and unoccupied. How can it cost more to do these things in the government yards, where the plant all belongs to the same owners and no percentage is charged on the investment, but the whole expense is simply for the material and labor required?

The Coast Guard of Great Britain was an organization formerly intended to prevent smuggling and protect the revenue merely, but is now constituted so as to serve as a defensive force also, and such would be the case with our Revenue Marine if combined with the

Navy. The old coast-guardsmen of England were in the employ of the customs department, but in 1856 the Coast Guard was transferred to the Admiralty. The coasts of the United Kingdom are divided into districts and each placed under a navy captain, who has a guard-ship at some port in the district. All the revenue cutters are attached as tenders to these ships and manned therefrom. The whole organization is disciplined and drilled and kept in efficient condition for service, and in time of war all these men may be called upon to serve as man-of-war's-men. The guard-ships are also employed as training-ships for the navy. This becomes an excellent and additional school of practice for officers, something which we need so much in time of peace.

The Life Saving Service would naturally follow the transfer of the Revenue Marine to the Navy, because it is now managed by officers of that service. This would render the whole system thoroughly homogeneous and place it practically under one head. No part of the coast would be out of the view of the coast-guardsmen, who could always be at hand to give aid to sufferers or to telegraph information to headquarters.

The Coast Survey is a sub-department of the government where the sphere of usefulness of naval officers might be greatly extended with advantage to the country and the naval service. Naval officers are now employed on that service to a limited extent, in making hydrographic surveys to determine the coast-line of the United States; and in making charts of harbors and tide-waters, and of the bottom of the ocean along our coast. But the small appropriations made available for that service impede greatly its usefulness. Its operations fairly commenced in 1832 with a survey of New York harbor, and were extended to the eastward and southward, continuing later to the Gulf and Pacific coasts. It is still going on, and there is yet much to do; besides, the early work has to be gone over in many cases. The hydrographers of forty years ago had neither the knowledge, the instruments, the experience nor the precision which they now have; and the physical changes have in some places been very great, so that new surveys are necessary. What can be done, with limited means and few men, is being done by our Coast Survey; but it is high time our coasts were all mapped out, and the approaches to our harbors thoroughly surveyed, and the charts in the possession of navigators. This would give an impetus to our coastwise commerce which would richly repay the country for the amount expended.

The Coast Survey Service naturally belongs under the supervision of the Navy Department, but was, unfortunately, located in the Treasury, because its originator and first superintendent was in the employ of that department as Superintendent of Weights and Measures. The vessels of this service do not belong to the navy, but the men and officers employed on them do, and are paid from the naval appropriation. This service affords a most excellent and necessary school of practice for naval officers. Not only do they gain valuable experience in handling the vessels and managing their affairs, but they become thorough masters of chart-work and practical navigation on pilot ground. Every nook and corner of our coast becomes familiar to them, and they learn the name of every shoal and rock, the depths of water over them, the marks by which they are distinguished, and the ranges by means of which they are located.

If these nautical branches of the civil service were located where they certainly most appropriately belong, under the intelligent supervision of the Navy Department, it would necessarily extend the sphere of usefulness of navy officers and be a great advantage in many ways. Officers, whose promotion is now so very slow, must spend long years in the subordinate grades; and after a certain amount of necessary work in regular naval cruisers, many of them would be very glad to have service in the civil branches. This would relieve them from the monotonous grind of naval routine, give them more independent and responsible duty, and keep them profitably occupied. The many little steamers of these services would give them abundant experience in their management and handling, and a just confidence in their own powers. Their knowledge would be increased and their natural abilities quickened, as it never can be done by keeping them continually employed in subordinate duties, with no opportunity for independent action or the assumption of responsibility. After long years of subordinate service, during which an officer's ambition is broken and his zeal quenched, when at last the opportunity arrives for individual action he is quite likely to find he has been so accustomed to leaning upon others, and being guided and directed by them, that he is unfit to stand alone. In every calling there must be some stimulus offered to the ambition of those who enter it, and a reasonable prospect of advancement as well as security.

These services would also afford excellent places for the men as a reward for faithfulness and long service. After a certain number of continuous re-enlistments for active service in the regular navy, the

men could enjoy more comfortable and less arduous duty in the civil branches, where they would be nearer home. And their ripe experience and training would be always available in the hour of need. The records of their service would be kept in the same office and their history thoroughly known. Such men would form a valuable nucleus for the training of new levies, when expansion was necessary.

The Hydrographic Office was instituted in the Navy Department, for the purpose of improving the means for navigating safely the vessels of the navy and of the merchant marine; and here should be located the Coast Survey interest, for it is a needless expense to keep up two separate establishments, with such similar aims, in different branches of the general government. Navy officers are employed in the work of this office, but their sphere of usefulness could be largely extended by more liberal appropriations for this important service. By far the largest part of the earth's coast-line has been only approximately surveyed, and in many places only the general direction and aspect of the coast is given, so that the navigator must be constantly on his guard against hidden dangers. The Hydrographic Office has charge of the preparation of all charts of foreign coasts, while the Coast Survey Office looks after those of our own. Good policy and economy would seem to dictate that these interests should be combined. The former, unfortunately, has in service but one surveying vessel, which is doing valuable and much needed work on the Pacific coasts of Mexico and Central America. These surveys of foreign coasts should always be assigned to special vessels charged with the duty of making charts, and sent abroad with officers specially detailed for this important part of the naval work. The extension of our commerce requires a systematic examination of many reported dangers in the Pacific and Atlantic oceans, and a thorough survey of the Pacific and parts of the West India islands and the Spanish Main. Experience teaches that men shun hidden dangers, and if the danger, though known to exist, has no precise location, navigators will lose valuable time in endeavoring to avoid it. Those bold navigators who in the early days literally took their lives in their hands, and in their wretched little caravels penetrated into unknown seas, are entitled to every praise; but in these modern days of large and valuable steamers, with their quick movements and accurate courses, it is more than ever necessary they should be able to pursue their way with confidence and security.

The meteorological division of the Hydrographic Office could profitably employ many more officers. In this division, the information gained by the experiences of navigators in every sea is collated and analyzed, for the purpose of affording complete knowledge of ocean meteorology. Probably none of the arts has benefited to so large an extent by the labors of meteorologists as navigation. The knowledge thus acquired of the prevailing winds during different seasons of the year, of the regions of storms and calms, and of the laws of storms, has caused a great saving of life and property, and by pointing out the most expeditious routes to be followed, has shortened voyages to a remarkable degree. The science of meteorology has made rapid progress of late, since proper instruments have been invented for making correct observations with regard to the temperature, the pressure, the humidity and the electricity of the air. And since simultaneous observations over such vast regions have been instituted, all these data are accumulated from records sent in by the national and merchant marine. The work of reducing and grouping the observations is slow and tedious, and requires technical knowledge. It is the design of the Hydrographic Office to publish wind and current charts and pilot charts of all the oceans, and it is only through lack of adequate force to compile and reduce the data that it is not more rapidly executed. With these charts at hand one can see at a glance the past experience of hundreds of navigators, regarding the weather and currents at any season and in any locality, and one is thus enabled to select the best route for a short passage. With this knowledge an officer can navigate his ship or lead his squadron at a given season through the seas where they will be the least baffled by head winds and will make the finest run. We know that the question of the best route for a merchant ship between two ports is of the utmost consequence, and for a naval cruiser in time of war it might be of incalculable importance to the nation.

I have already stated that whenever officers of the national government are required, of nautical skill, in the performance of duties connected with the merchant marine, naval officers would be the best persons to employ. Our merchant navy has never received the attention bestowed upon other great national industries ; probably because it has not due representation in the government. It would be a great advantage to the vast national interests coming under this general head to have them all grouped together in one responsible bureau having the necessary power to act. The merchant marine has now

no direct or special representative in the highest council of the nation, but the various interests bearing on this subject are scattered through the different departments, and it is left without that active support and fostering care it so much needs.

England has a permanent department in her ministry known as the Board of Trade. It is the business of this board to execute all laws relating to the merchant marine, to watch foreign events, especially foreign maritime legislation, and to prepare bills for parliamentary action whenever the exigencies of commerce require it. It maintains a steady watchfulness over all circumstances affecting maritime affairs, and proposes opportune legislation for the benefit of British interests. Hence their present Merchant Shipping Act, an almost perfect codification of the experience of centuries, under which the Board of Trade regulates the local marine boards for the surveys of vessels, the shipping and payment of crews, and the examinations of masters and mates. The Board of Trade provides savings banks for the deposit of seamen's wages, and manages a pension fund for relief of disabled sailors and the support of their families. It controls pilotage and pilots under uniform laws, investigates wrecks, collisions and casualties, punishing incompetence, negligence and fraud. It superintends the accommodations for emigrant and other passengers, controls the lighthouses and beacons, and enforces all the maritime laws of the kingdom. Unfortunately, the United States have no Board of Trade, or any Merchant Shipping Act or commercial code worthy of the name. We have no political machinery for concentrating the power of the government on this vast interest, which is therefore much neglected. This is a defect which cannot be effectually supplemented by the spasmodic action of Congress; and commercial bodies, or the guilds of ship-owning and ship-building, cannot be expected to administer the law or inspire every change necessary. All such management of our enormous foreign and coastwise trading interests must be fitful, tardy and uncertain. The best talent and the most persevering watchfulness must be always and systematically devoted by us, as by England, to administering and improving maritime legislation, or we will always be laggards in the race.

We should therefore establish a Bureau of Commerce in the executive branch of the government, and when its machinery is in vigorous operation we may hope to contend successfully with our old and now dominant rival for the empire of the seas, and have an audible voice in the control of our own trade. The proper place to locate

such a bureau is naturally in the Navy Department. Naval independence is essential to our national welfare, and to secure naval power all our shipping interests should be united and organized. They should be appropriately represented in the general government, where their voice may be heard and their influence felt, their rights maintained and their wants made known. Give, then, to the Navy Department all that bears on the protection of our commerce both at home and abroad. This would involve the inspection and supervision of the *matériel* and *personnel* of the merchant marine, so far as it devolves on the nation, and would very materially increase the sphere of usefulness of navy officers, besides being of great benefit to the country.

When we shall have relieved our merchant marine from the many burdens which have wellnigh blotted it from existence, we should offer liberal inducements to any owners who will have built such ships as can be efficiently appropriated for war purposes. There is no good reason why our steamers of commerce should not be planned so that in an emergency they could readily be converted into fit vessels for naval purposes in time of war. Build them upon such plans and give them such speed and tonnage as may be approved by the naval authorities. Let them be employed in carrying our foreign mails and commerce, officered from the navy, and liable in case of war to be taken at any time under charter by the government. With some special strengthening and certain modifications in the arrangements of bulkheads, a large number of merchant steamships might be utilized for war purposes, and sufficient inducement could readily be offered to shipowners as a reward for the introduction of these modifications. In England many shipowners have seen their way to comply with the wishes of the government in this respect, and have been rewarded simply by a preference in letting contracts over those not so arranged. A fleet of armed merchant steamers would constitute an excellent auxiliary force, and though they could not cope with the heavy men-of-war of the enemy, they might injure his commerce, and could meet his light unarmored cruisers on an equality. Thus we could reinforce and strengthen our navy in the most economical and expeditious manner, and at the same time promote and encourage our merchant marine in the most practical way.

Merchant marine training ships should be established and managed by navy officers. The character of our seamen has sadly degenerated in the last quarter of a century, and the ratio of Americans to be found in our ships is very small. The remedy for this is in a wisely organ-

ized system of training schools for seamen, and the government will have to be the prime mover in the matter, its appropriations developing and perfecting the system for both the navy and the merchant marine. So that when once again our flag shall have attained a position on the sea commensurate with the dignity and needs of our great nation, we shall not be under the painful necessity of calling on foreigners to command and sail our ships, and may be spared the mortification of having to man our guns with those who are not Americans. All the great maritime nations of the world except our own have established systems of training for their merchant marine. In England there are nineteen large training ships for boys and two for officers, while in our country there is but one merchant training vessel, and that, in charge of naval officers, forms a part of the public school system of the city of New York. The better trained and the more intelligent our sailors become, the fewer will be the shipwrecks and the less the loss of life and property. The aggregate losses at sea every year are astounding, and probably two-thirds of the wrecks are the result of ignorance and incompetence. Hence the importance of seeing that those who manage our ships are fitted in all respects for the duties they have to perform, and this great trust could not be committed to better hands than those of naval officers. Authority might reside with the bureau having charge of commerce to examine officers as to their fitness, with power to issue certificates and convene courts of inquiry for examining into all marine disasters, and to punish negligence or ignorance by revocation or suspension of certificates. Some uniform and responsible system is necessary.

Shipping commissioners are appointed by the general government for our principal ports, whose duty it is to afford facilities for engaging seamen by keeping a register of their names and characters; to provide means for securing the presence on board at the proper times of men who are engaged; to facilitate the making of apprenticeships to serve in the merchant marine, and to perform any other duties relating to merchant seamen or merchant ships that may be required by law. These commissioners are appointed for the protection of seamen in our ports and vessels, and their duties should be performed by men who have the welfare of seamen at heart, otherwise the office may become only an additional engine of oppression, rendering the sailor's condition worse than before. The temptation to multiply fees, which the wording of the law presents, should be removed and the officers brought under executive control, for at present no particular

supervision is exercised over them. It is high time we began to look after the interests of our sailors on shore, and to endeavor to emancipate them from the clutches of the land-sharks who rob them of half their wages and continue to hold a perpetual mortgage on them. Effective means should be devised to put an end to the outrages that are perpetrated continually on those without whom we cannot hope to revive our drooping marine. Sailors would be more provident, more independent and better able to take care of themselves, by stopping the payment of advance wages to them. This has been done in England, and is found to work well, and should be effected with us. To this system of advance wages, more than anything else, is due the largest portion of the seaman's troubles. It is through such payments that boarding-house keepers are enabled to fleece the sailor by exacting extortionate, and in many cases purely fictitious, board and rum bills, thus sending him penniless to sea. He is frequently cast ashore before his advance is worked out or with little or nothing due him, and he must then put himself in the power of the keeper again, who obtains his pay from the next advance, and so on. The sailor should make his own bargain with the captain, as the sailmaker, steward and carpenter make their own contracts; then he will become a man like one of them, and will go to sea cheerfully to earn his own money instead of working reluctantly for the benefit of his landlord. And then, too, will be broken up the illegal business of shipping-brokers with their "blood money," which cannot be stopped so long as sailors receive advance-wages. No better or more capable and appropriate men could be selected to look after the duties of shipping commissioner than naval officers.

The Marine Hospital Service is the medical department of the merchant marine, and is charged with the duty of preserving the health interests of those officers and seamen whose services are absolutely necessary to the maritime greatness of the nation. The sphere of the naval medical service might be profitably enlarged to include this important duty, and it would afford a fine field for increasing the usefulness of naval officers. It would be a good move in the direction of economy and efficiency to unite these services and have the supplies and management combined under one head. And in connection with the shipping offices it would give the Navy Department a complete record of the merchant sailors of the country. The hospitals belonging to this service are erected and maintained at the expense of the United States, and it would certainly simplify matters

to have them under the same management as the naval hospitals. The expenses of this service are defrayed out of the Marine Hospital Fund, which consists of hospital dues assessed and collected in accordance with law out of the wages of the seamen, at the rate of forty cents a month while actually employed. Thus the seamen, when ill, are cared for, not as a matter of charity, but of right, in an institution sustained by themselves, and all who become disabled, from disease contracted or injuries received in the line of duty, are entitled to its benefits. But the records show that a large number of the patients admitted are persons who were never physically fitted to be seamen and who should never have been permitted to ship. It would seem just to require some moderate physical standard for shipment in the merchant service, and the passage of a law requiring the compulsory examination of seamen would probably be a measure in the true interests of our commerce, and it is certainly the only means of keeping our crews free from persons physically incapacitated for seafaring pursuits and utterly unavailable in case of war.

Our pilot interests would doubtless be better managed under government control, and there are many reasons why the national government should assume general direction of pilotage. A national pilot law that would call into existence, under the control of the Navy Department, pilot commissioners for all the great ports of the country, with uniform regulations, strict accountability, low charges and thoroughly competent and efficient pilots, would certainly prove very advantageous to our commercial marine. The laws of different States bordering on the same navigable waters frequently conflict, and this makes it the more important that the general government should define the necessary pilot rules on all the public waters of the nation. Here, again, the sphere of usefulness of navy officers could be profitably extended.

The Steamboat Inspection Service naturally belongs under the control of the Navy Department, and this would afford an appropriate field for the employment of navy officers. The supervising inspectors of steamboats are chosen for their knowledge, skill and practical experience in the uses of steam for navigation, and are required to be competent judges of the character and qualities of steam vessels and of all parts of the machinery employed in steaming. It is their duty to confer with and examine into the doings of the local boards of inspection within their districts. The local boards are made up of the inspector of hulls and the inspector of boilers in each district, and

have very responsible duties to perform. The inspector of hulls is required to have a practical knowledge of shipbuilding and navigation and the uses of steam in navigation, and to be competent to make reliable estimates of the strength, seaworthiness and other qualities of steamers and of their equipment. The inspector of boilers must have practical knowledge and experience of the duties of an engineer employed on steamers, and understand the construction and use of boilers and machinery and their appurtenances, so that he can form reliable opinions of their strength, form, workmanship and suitableness for the purposes intended. Besides satisfying themselves that the steamers which come under their inspection are in every way safe and reliable and properly fitted, these boards have to license and classify the officers and pilots of such vessels, and investigate all their acts of incompetency and misconduct. They are also required to see that passenger steamers are properly manned and officered, and to define the number of passengers they shall carry. The requirements of this service should be extended to sailing vessels as far as applicable in order to make the government supervision of our merchant marine complete.

It would be a great advantage to have a competent naval officer attached to the American legation in every important maritime country. All the leading nations except our own have such officers attached to their principal legations, whose business it is to investigate and report on the administrative methods of other governments in regard to naval affairs, and upon all experiments, improvements, changes and occurrences of interest in naval matters. Other governments have of late singularly improved the science of naval administration; they do more things, and do everything with more order, more celerity and less expense than ourselves. During our time a complete revolution has taken place in naval affairs, with which we have failed to keep pace. We might with profit learn many things from the nations whose custom it is to maintain great navies; and it would be a benefit to have special agents required to observe and report upon such matters. Every one conversant with naval affairs feels aware that our system of managing these things is not perfect; and yet it might be difficult, unhesitatingly, to point out just what are the defects, or to suggest the necessary measures of reform. Our bureau system is very well as far as it goes, and attends to an immense amount of detail and routine; but would it not be better to have them united more definitely, and made more distinctly respon-

sible and accountable to some practical head or commission, with the necessary power and technical knowledge to direct? In England, the naval lords of the admiralty do this, and in France the Minister of Marine is generally a naval man, besides having in his office naval experts to assist in the direction.

There would be no trouble about securing proper officers for any of the services here suggested, and many would gladly fit themselves for them if there was any probability of their being employed. If the educated naval officer is not fitted for any of the duties here proposed, then his education has, to a great extent, been useless. The more openings that can be made for the useful employment of naval officers in time of peace, the greater inducement there will be among them for improving their talents and their opportunities, and the general result will redound to the credit of the country and the improvement of the naval service. The country has a right to expect a great deal of those it educates and keeps, and I am sure, so far as navy officers are concerned, they thoroughly appreciate their obligations and are full of desire to serve. They are anxious to maintain the reputation of the service; to secure a high place in the good opinion of the people, whose servants they are, and to deserve their respect, affection and willing support. The great trouble is, they do not have sufficient opportunities for coming in contact with the people, and displaying their ability to serve them efficiently and well in many public duties having a direct bearing on their own special calling. Nor are the people generally acquainted with the navy officers, neither do they know what faithful, loyal and capable public servants they are, ready at all times and anxious to do much more than they are permitted to do.

Every naval officer should, of course, endeavor to contribute to the advancement and improvement of the service, since its character depends on those who form it. Each should be properly furnished in mind and library with all that bears on his calling, or on his special department of the service. He should master his profession or his branch of it; but that is not enough. Those officers who have done the best, and accomplished the most for themselves and their country, have gone beyond the mere call of routine. They have chosen their specialties according to their tastes, and have relieved the burden and monotony of their daily duties by a few hours devoted to general culture and congenial accomplishments, thus increasing their value as members of society, and so quickening their intelligence as to

make them the ready masters of their work. It is not desirable that officers should neglect their duty for some other calling, but that they should enrich themselves and their profession as much as possible without encroaching on the just demands of the service. If we are faithful, industrious, earnest, and of noble spirit, our sphere of usefulness cannot help being enlarged; but if we are idle, careless, fault-finding and contentious, it will be contracted continually. A house divided against itself cannot stand, and the navy can never secure that place it deserves in the hearts of the people but by united effort and earnest self-control. If good feeling and sympathy pervade its various branches, and all work together for the common good, there is nothing we should enjoy that is impossible to us. But if there are bickerings and jealousies and envyings, and a pervading spirit of detraction, these will not tend to enlarge the reputation of the navy or increase its sphere of usefulness.

NAVAL INSTITUTE, WASHINGTON BRANCH.

APRIL 26, 1883.

COMMANDER JOHN R. BARTLETT, U. S. N., in the Chair.

THE THEORY OF THE DEEP SEA WAVE.

BY ASSISTANT NAVAL CONSTRUCTOR RICHARD GATEWOOD, U. S. N.

The mathematical theory of the rolling of ships in a seaway is now so well established in all its main features as not to admit of doubt as to its principal deductions affecting the methods of obtaining desirable qualities in ships. Here, however, the disagreeable fact obtrudes itself that all ships, and especially war ships, are in their qualities only compromises, the prominence of the individual qualities aimed at depending on the circumstances of their design.

It is both as leading to the higher and more important subject of the rolling of ships, as well as for the intrinsic interest of the subject, that I have undertaken the present paper. And if this attempt meets with any degree of success, it is proposed at some future time to lay before you, as far as propriety in a paper and my own limited time and knowledge will admit, the present state of the mathematical theory of the rolling of ships.

I had originally intended to include in the paper some remarks on the observation of waves, but as, in order to be reasonably complete, it has lengthened itself out further than expected, I must refer especially to the article on "Deep Sea Waves," in that valuable book, which I think no naval officer having to do with the construction or handling of ships should be without, "A Manual of Naval Architecture," by W. H. White, Esq., late chief constructor to the British Admiralty.

In order to simplify matters somewhat, the only difficult mathematical portions of the subject have been embodied in the form of an

appendix, leaving in the body of the paper the essential simpler portions.

The present accepted trochoidal solution of deep sea wave motion was arrived at independently about the same time by Mr. Froude and Prof. Rankine. The former's solution is the more instructive, while the latter's is more complete and rigidly mathematical. The analytical solution in the appendix is based upon that of M. Bertin, as published in "Naval Science" for October, 1873, and will, I think, be found very instructive by the mathematical student of the subject.

Many sources of information have been made use of, but the writer is particularly indebted to the various articles on the subject by Mr. C. W. Merrifield, M. Bertin, and others, in "Naval Science," and especially to the able lectures delivered by Prof. James H. Cotterill, M. A., F. R. S., and his assistant, Chief Engineer T. A. Hearson, R. N., at the Royal Naval College at Greenwich.

Fundamental Conditions of Fluid Motion.

A perfect fluid in continuous motion is from its nature subject to certain fundamental conditions which must in all cases be satisfied. The first of these, known as the Condition of Continuity, expresses the fact that the mass of each elementary volume fixed in space within the fluid is constant. The second expresses the principle of d'Alembert, governing the motion of all matter, viz. that at every point of a system the reversed effective forces are *in equilibrio* with the impressed forces; or, for fluids, that the effective force acting on each particle to produce acceleration is the resultant of its weight and the pressure of the surrounding frictionless fluid. This is known as the Condition of Dynamical Equilibrium.

The mathematical expressions of these two conditions are essentially differential, and admit of an infinite number of solutions. In each particular case there are, in addition, what may be called the boundary conditions, such as the form and position, or the state of pressure, or other peculiarity of the boundaries capable of affecting the adjacent fluid motion.

If, in the mathematical study of particular cases of fluid motion, a functional motion be found satisfying the necessary conditions of continuity and dynamical equilibrium and the particular boundary conditions, then its physical interpretation must denote a possible scheme of fluid motion, the identity of which with the particular observed motion can be tested experimentally by observation of the physical

conformation, and of the "dynamical structure," or qualities of the motion at different points; and a further important check may be applied by the conformity of the mathematical motion with the necessary conditions of formation of the observed motion from the fluid in its initial condition by observed forces.

It is by one or more of these tests that certain refinements have been imposed upon the mathematical theories of such comparatively well known motions as the solitary wave of translation and the deep sea wave or swell.

Steady and Unsteady Motion.—Stream Lines.

In continuous motion the magnitude and direction of the velocity at a point is a function of the coordinates of the point and of the time. When this function does not involve the time explicitly, that is, when the velocity at a particular point is constant in magnitude and direction, the motion is characterized as "steady." When the time is explicitly involved, the motion is called "unsteady." It follows from this definition of steady motion that the particles passing through each point describe curves of invariable form, called "stream lines," so that the motion of the whole current may be represented by drawing a series of such lines, within which the flow takes place as if in material frictionless tubes.

The cases of greatest importance in fluid motion are either cases of steady motion or may be reduced to it. Thus, if a wave have invariable form, the corresponding motion may be reduced to steady motion by ascribing to the whole system a velocity equal and opposite to that of propagation, when the eminently unsteady wave motion becomes steady or stream line flow through the wave form.

Wave Motion in Perfect Fluids.

According to our conception of wave motion in fluids each particle performs a certain excursion of small extent as compared with the motion of the wave form, the path of which may be open or closed, while corresponding adjacent particles occupy such phases of the same or different individual motions as to form undulating profiles, virtual or actual. Open paths necessarily involve bodily translation of the individual particle, and are distinctive of so-called waves of translation, on the passage of which any small floating body finds itself transferred onward through a certain distance; while closed paths

correspond to purely oscillating waves. A combination of the two in any proportion, producing looped orbits, also exists in nature.

In expansive fluids, or gases, the excursions may all be in rectilinear paths parallel to the direction of propagation of the wave in a virtual profile of rarefaction and condensation, as in the case of common sound waves. An infinite variety of other motions is, of course, possible.

In liquids, being incompressible, all the particles cannot move in such paths—although individual particles may—since this evidently involves interpenetration.

Neither, under the action of natural forces are vertical rectilinear paths possible for longitudinally successive particles, for otherwise the particles on the slope would tend to slide down the profile under that component of the acceleration which is at right angles to the normal to the surface, just as raindrops before being absorbed by the mass of water are often seen running down the wave slope.

Thus in the wave motion of liquids under the action of natural forces the paths of the excursions of individual particles must in general have both horizontal and vertical extension, or the particle must in a complete excursion be subject to both horizontal and vertical acceleration, excepting particular particles which may experience only the former or the latter, such points being points of change of sign of the latter or the former. No other cases seem possible.

Certain paths suggest themselves as probably fulfilling these general conditions.

We may obviously have rectilinear paths of properly varying inclination, from particle to particle, and this condition approximately obtains in all standing wave systems, or waves which have no motion of propagation, but rise and fall on the spot, crest and trough alternating at the same point but never occupying intermediate points. An instance of approximately such wave motion in a currentless fluid is what is known as a Chopping Sea* caused by reflection of running wave formations by steep banks, with consequent superposition of more or less symmetrically opposite running systems. The so-called pyramidal sea, observed after passing the eye of a cyclone, is a very marked instance of this chopping motion.

* For perhaps the best investigation of this motion, reference may be made to the article entitled "Notes on Waves and Rolling," by M. L. E. Bertin, in "Naval Science" for Oct. 1873.

Motion in paths either open or closed, involving properly changing values of vertical and horizontal acceleration for the same particle occupying successive positions in the wave form, are also evidently possible. Such motion in *open* paths occurs in what is known as the Solitary Wave of Translation, first investigated by Mr. J. Scott Russell as to its mode of formation and its elements.*

Running Wave of Pure Oscillation.

The elementary running wave of pure oscillation must then involve for the individual particles oval paths or orbits, the mathematical expression of which in each case of motion must fulfil, as we have seen, certain conditions, viz.

(1) The Condition of Continuity.
(2) The Condition of Dynamical Equilibrium.
(3) The Boundary Conditions.
(4) The Conditions of Formation.

For the essentially differential expressions of conditions (1) and (2) reference may be made to the appendix. In the body of the paper we shall content ourselves with examining the physical limitations which they imply.

The boundary conditions are, in general, the depth and conformation of the bottom and the state of pressure on the upper surface of the fluid. The latter is generally assumed as that of uniformity, but it may be well to remark here that this may not be strictly correct, because since the upper surface is in contact with the atmosphere, it is not, in the strict sense, a free surface, but rather the surface of separation of two fluids, the one liquid and incompressible, the other gaseous and compressible, and generally having some motion relatively to the wave form. It seems a necessary consequence that by the passage of the long series of waves contemplated in the trochoidal theory, the air must experience a tendency to set up a corresponding wave motion, possibly influencing the condition of pressure at the surface of separation.

The conditions of formation generally involve some estimate of the perfectness of the actual fluid, the initial condition as to "molecular rotation,"—a somewhat complex quality, involving a sliding over one another of successive layers, a grinding action, so to speak; or in other words, an initial current of velocity varying with the depth

* Reference may be made with advantage to the original paper in Report of British Association for 1844. This motion is of great interest.

below the surface—and some particular conception of the action of wind on water.

A fairly good idea of the physical nature of "molecular rotation" may be obtained by considering a small sphere anywhere in the fluid to become suddenly solidified and removed from the remaining fluid, when, if the sphere retains only a motion of translation—which may vanish—the fluid motion is said to be "irrotational." If, however, a rotation about its centre of gravity appears, the motion is "rotational." Such motion evidently requires for its generation a force equivalent to internal friction, and hence cannot be generated or destroyed in a *perfect* fluid by natural forces. Thus if fluid motion is once irrotational it is always so. We have then as a consequence that *no wave motion involving molecular rotation can be generated by natural forces from a perfect fluid at rest* (and therefore irrotational), and this is one of the tests which the conditions of formation imply.

In the investigation of the deep sea wave we will apply the differential conditions (1) and (2) to an assumed mathematical motion, and consider the boundary conditions (3) as implying infinite lateral extension of the fluid, infinite depth, and a free surface at the atmosphere. Having found a simple functional motion fulfilling these conditions, we will investigate its qualities and dynamical structure, and finally test its value as a working hypothesis by applying the conditions of formation (4) in so far as they are understood.

The experiments of Gerstner, the brothers Weber, Scott Russell, and Stokes have completely demonstrated the fact that in simple oscillatory waves, the paths of the particles are ovals not to be distinguished from ellipses, and which become flatter as the bottom of the trough is approached. Further, the deeper the water the rounder are the elliptical orbits of the surface particles.

Accordingly, if we assume the ellipse about the centre as a not improbable and a simple case, the equations of the corresponding steady motion become, with axis of x the horizontal through the surface orbit centres negative in the direction of wave propagation, and that of y the vertical upwards through a crest,

$$x = Vt - a \sin \frac{\pi}{T} t$$

$$y = -h + b \cos \frac{\pi}{T} t$$

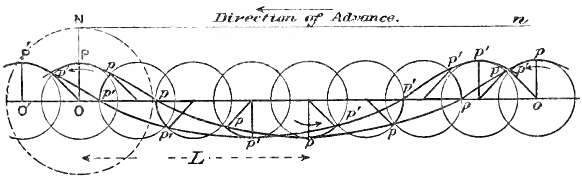
where V is the speed of propagation, a the horizontal, and b the vertical axes of the ellipse whose centre is at a depth h below that of the surface, and T the half period. It is shown in the appendix

that this motion is only possible for the case of $a = b$, when the ellipse becomes a circle.

This motion in circular orbits with uniform angular velocity of successive particles in wave profile is called trochoidal wave motion, and is that now universally adopted as expressing with sufficient accuracy the motion in a regular group of waves in mid-ocean after the producing wind has ceased, and accordingly taken as the basis of the investigation of the behavior of ships in a seaway.

Trochoidal Wave Motion.

Our theory then contemplates for the surface a series of particles in successive phases of motion in circular orbits, with uniform angular velocity in a vertical plane at right angles to the wave ridge. Thus let us have a wave of length $2L = \lambda$ and height H [$= 2r$ evidently, r being the radius of the surface orbits.] Lay off $Oo = 2L =$ the wave length,

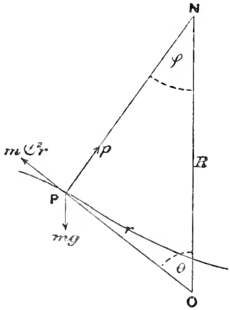


and divide it into any number of equal parts, say 8, and at the points of division describe circles of radius r. At O, assumed as the crest plane, the particle is at the highest point of its orbit and moving with the wave as at P. Dividing the orbit into 8 equal parts, lay off points p on successive circles with angular positions increasing from the vertical in a direction opposite the hands of a watch by increments of 45°. The curve line Pp . . . through these points is the corresponding wave profile. Let us now suppose that at the proper interval of time, each particle has moved through one increment in its orbit, when the wave profile is $P'p'$ . . . or the wave has advanced or been propagated through the distance OO'. Each particle, however, has moved through the much smaller distance pp', the ratio being for ordinary ocean waves $\frac{1}{8}$ to $\frac{1}{7}$.

The form of the profile may evidently be described by a point P on the radius ON of a circle of radius $ON = R = \frac{2L}{2\pi}$ rolling along the horizontal line Nn, since the angular position of P from

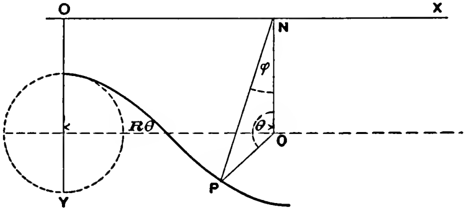
the vertical is always proportional to the linear advance of the centre O. The trochoidal curve is markedly more peaked at crest than at trough, and more so the higher the wave in proportion to the length, the limiting case when $r = R$ or $\frac{H}{L} = \frac{2}{\pi}$ corresponding to a cycloid or cusped curve shown in the wave diagram accompanying the paper. This cycloidal wave is the theoretical breaking wave, because if the ratio $\frac{H}{L}$ increase further the curve becomes looped, evidently involving discontinuity in the fluid. As a matter of fact, waves break long before this condition is reached, and there are theoretical reasons for believing that deep water waves, not involving molecular rotation, never reach a sharper ridge angle than 120°, or 30° of slope at the breaking cusp.

Dynamical Equilibrium of the Trochoidal Surface.—Let ω be the angular velocity of a particle in its orbit, so that $R\omega = \frac{L}{\pi}\omega = V$ the speed of advance. The particle P of mass m (say) is acted on by (1) gravity, vertically downwards, (2) the acceleration of the centrifugal force towards the centre O, and (3) the resultant pressure of the adjacent fluid particles, which must be normal to the surface at the point P. By d'Alembert's principle the resultant of any two of these must be equal and opposite to the third reversed. Thus reversing the acceleration of the centrifugal force to act at P outwards along OP, the forces shown at P must form a system in equilibrium. From O lay off ON vertically to represent the force of gravity g on the same scale as $OP = r$ may be taken to represent $\omega^2 r$ the centrifugal force on unit mass at P. Then $\frac{ON}{OP} = \frac{g}{\omega^2 r}$ or $ON = \frac{g}{\omega^2}$. Join PN, then PNO is the triangle of forces for P, and



PN represents, in magnitude and direction, the resultant fluid pressure at P. Thus, for dynamical equilibrium, PN must be normal to the surface at P. Now this holds for the trochoidal surface through P for which $ON = \frac{g}{\omega^2} = R$, the radius of the rolling circle; for, considering the mode of generation of the trochoid, N, being the point of contact of the rolling circle with its base line, is obviously

the instantaneous centre of every point rigidly attached to the circle, whence the motion of P in the trochoid must at each instant be perpendicular to PN. This important fact may be shown analytically, thus:



With origin and axes as shown, we have for the equation of the trochoid

$$x = R\theta - r\sin\theta,$$
$$y = R - r\cos\theta.$$

Thus at P, corresponding to the angle θ, we have

$$\frac{dy}{dx} = \frac{\frac{dy}{d\theta}}{\frac{dx}{d\theta}} = \frac{r\sin\theta}{R - r\cos\theta},$$

the inclination of the tangent to the horizontal or of the normal to the vertical. Also in the triangle of forces, we have resolving horizontally and vertically

$$p\sin\varphi = m\omega^2 r\sin\theta,$$
$$mg = p\cos\varphi + m\omega^2 r\cos\theta,$$
$$\text{or } \tan\varphi = \frac{r\sin\theta}{\frac{g}{\omega^2} - r\cos\theta},$$

which is the same as the above, provided

$$R = \frac{g}{\omega^2},$$

a condition therefore necessary for dynamical equilibrium.

It may be here noticed that the slope is a maximum when $\cos\theta = \frac{r}{R}$ or OP is perpendicular to PN, when it has the value

$$\varphi = \tan^{-1}\frac{r}{\sqrt{R^2 - r^2}},$$

or is given by $\sin\varphi = \frac{r}{R} = \frac{\pi H}{\lambda}$. The point of inflexion or maxi-

mum slope is therefore above the mid-height, where $\theta = \frac{\pi}{2}$ and $\tan \varphi = \frac{r}{R} = \frac{\pi H}{\lambda}$, the value of the maximum slope of the curve of sines wave of same dimensions, in which case, however, it is at mid-height.

Virtual Gravity.—We have seen that the line NP measures the resultant force on the particle on the same scale as ON represents the force of gravity, and is thus for wave motion the analogue of gravity in still water, since evidently the rate of increase of the fluid pressure in a direction normal to the surface is measured at any point by the corresponding length of this line, whereas in still water it would be measured by the length of ON or gravity. It is hence called the virtual gravity at the point. Thus for a subsurface of uniform pressure infinitesimally near the surface, the normal thickness of the layer at any point must be inversely proportional to the corresponding virtual gravity, or if z be this normal thickness and n the value of virtual gravity, we must have all along the layer $nz =$ constant, the second condition necessary for dynamical equilibrium.

Virtual gravity is obviously a maximum at the trough and a minimum at the crest, and is equal to gravity at a point between the point of inflexion and the mid-height for which $\cos \theta = \frac{1}{2} \frac{r}{R}$.

Relation between the Elements of a Trochoidal Wave.—From the equation $R = \frac{g}{\omega^2}$, we have

$$V = R\omega = \sqrt{gR} = \sqrt{\frac{g\lambda}{2\pi}} = 2\tfrac{1}{4}\sqrt{\text{length}}\ \text{(nearly)},$$

in feet per second with the ordinary units. It therefore follows that the speed of the deep sea wave according to the trochoidal theory is a function of the length only and is independent of the height, a relation very well borne out in actual well-defined wave series experimented upon, but, as bearing on the accuracy of which, perfectly reliable experiments under favorable circumstances are still acceptable. As an example, mention may be made of the fine wave series observed by Commodore Wilkes off Cape Horn in 1839. His observations are thus described: *

"The Porpoise was directly ahead of the Sea-Gull, and but two waves apart; the rate of sailing was about eight knots an hour, both vessels being apparently very steady. In heaving the log, I found

* See "Narrative of the United States Exploring Expedition," by Charles Wilkes, U. S. N.

that the chip, in drawing in the line, was, when on the top of the next wave astern, distant by line three hundred and eighty feet, equal to one-sixteenth of a mile, and the schooner being on the next wave was twice the distance, or one-eighth of a mile. The time occupied for a wave to pass from the schooner to the brig was thirteen seconds, taking the mean of many trials, from which none varied more than a second and a half. This gave about twenty-six and a half miles in an hour for their apparent progressive motion. In order to get their height, I took the opportunity when the schooner was in the trough of the sea, and my eye on board the Porpoise in the horizon, to observe where it cut the mast. This gave me thirty-two feet. The waves ran higher and more regular on this occasion than I have seen them at any other time during the cruise."

In order to compare these observed results with the trochoidal theory, let us see what wave length would have caused the mean apparent period of six and a half seconds. Thus:

$$v = 8 \times 1.688 = 13.504 \text{ ft. per sec.} = \text{speed of vessels},$$

$$V = \sqrt{\frac{g\lambda}{2\pi}} = \text{speed of wave in ft. per sec.}$$

The vessels being two wave lengths apart, we should have

$$\frac{2\lambda}{\sqrt{\frac{g\lambda}{2\pi}} + 13.504} = 13,$$

the solution of which gives

$$\lambda = 371 \text{ ft.}$$

which must have been very nearly the true length, allowing for the sag of the line.*

The maximum steepness of these waves, according to the formula,

$$\sin\varphi = \frac{\pi H}{\lambda} = .27,$$

corresponding to an angle of $15\frac{3}{4}°$, an exceptional steepness for such long waves.

*It should be here noticed that since the relation of length and period is

$$\lambda = 5.123\,(\text{period})^2,$$

no comparison of averaged observed waves with the trochoidal hypothesis can be made without tabulating and averaging the square of the period; and this should in all cases be done. It follows that in the above comparison the length of the trochoidal wave is short because we have taken the square of the average period instead of the average $(\text{period})^2$; the latter will give a greater value for λ, though exactly how much greater cannot be determined, since there is no known relation between the mean and the mean square.

Another expression for the speed in terms of an experimentally obtainable function is

$$V = \frac{gT'}{2\pi} = 5.123\,T',$$

where T' is the wave period or the time in seconds between the passage of successive crests or troughs past a fixed point. Thus the speed of the second's wave is $\frac{g}{2\pi} = 5.123$ feet per second, or 3.034 knots per hour, a result which it is well to remember, as from it the speed of a trochoidal wave is easily obtained by multiplying by the observed period.

Also from the above the length of the second's wave is 5.123 feet, and that of any trochoidal wave is

$$\lambda = 5.123\,(\text{period})^2,$$

and the period of such a wave is

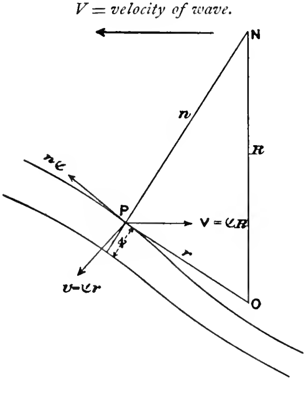
$$T' = \sqrt{\frac{\text{length}}{5.123}} = \tfrac{4}{9}\sqrt{\text{length}} \text{ nearly.}$$

It may also be remarked that we have

$$R = \frac{g}{\omega^2} = g\frac{T^2}{\pi^2}$$

or since $\frac{g}{\pi^2} =$ length of second's pendulum, R is the length of the simple pendulum whose time of oscillation is T' the wave period.

Condition of Continuity.—Imparting to the whole system a reversed velocity equal to that of the wave, the velocity at any point in the steady motion is obtained by combining with the velocity ωr in the wave form a velocity $V = \omega R$ in the direction shown in the diagram, when the triangle PNO becomes the triangle of velocities for P, and the resultant velocity of P in the steady motion is $n\omega$ in a direction perpendicular to NP. Accordingly if z be the thickness, measured on the normal NP, of an elementary stream adjacent to the surface, we must have for continuity in the stream line motion



$$n\omega z = \text{constant, or}$$

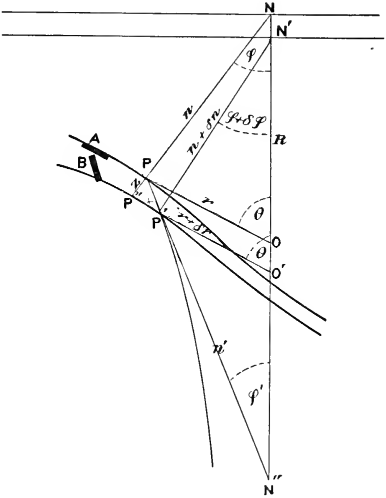
$$nz = \text{constant,}$$

the expression of the condition

of continuity, which is thus seen to be identical with that of the condition of dynamical equilibrium.

Subsurface Structure.—The investigation of the equilibrium of the trochoidal wave form applies unchanged to any subsurface of uniform pressure so far as its equilibrium *per se* is concerned. We will now examine what trochoidal subsurface, if any, ultimately very near the surface of the same length as the wave, crest under crest, will fulfil the purely geometrical condition $nz = constant$ imposed by both the dynamical equilibrium of the surface and the continuity of the stream line motion.

Conceive a trochoidal surface the line of orbit centres of which is $O'o'$ indefinitely near that of the surface. Then since R is the same



for both surfaces, NN' will be equal to OO', and $N'P'$ will be the consecutive value and direction of virtual gravity as we go downward to the lower trochoid, where $O'P' = r + \delta r$ is the orbit radius. Produce the surface normal at NP to meet the subsurface in P'' so that ultimately $PP'' = z$, and project the broken line $NN'P'$ on NP'', P' projecting on P'' with an error of the second order. Then we have

$$n + z = NN' \cos \varphi + (n + \delta n) \cos \delta\varphi,$$

and ultimately when $\cos \delta\varphi = 1$, the equation becomes

$$-\delta n = NN' \cos \varphi - z = \delta h \cos \varphi - z,$$

where $\delta h = OO' = NN'$; or, as we may write,

$$-n\delta n = n \cos \varphi \; \delta h - nz. \qquad (\alpha)$$

But from the triangle NPO, we have

$$r^2 = n^2 + R^2 - 2nR \cos \varphi,$$

or

$$n \cos \varphi = \frac{n^2 + R^2 - r^2}{2R}.$$

Also

$$n^2 = R^2 + r^2 - 2Rr \cos \theta, \qquad (\beta)$$

whence

$$\frac{n^2 + R^2 - r^2}{2R} = n \cos \varphi = R - r \cos \theta.$$

Substituting in equation (α), we have

$$-n\delta n = (R - r \cos \theta)\, \delta h - nz. \qquad (\gamma)$$

Differentiating (β) in terms of n and r, θ being constant, or, in other words, differentiating for an adjacent particle in the same phase, we have

$$n\delta n = r\delta r - R \cos \theta \, \delta r,$$

and substituting in (γ)

$$nz = r\delta r + R\delta h - (R\delta r + r\delta h) \cos \theta. \qquad (\varepsilon)$$

But since nz must be constant all along the elementary stream layer, its value must be independent of θ, the term in which must therefore vanish. Hence

$$R\delta r + r\delta h = 0,$$

or ultimately

$$dh = -R \frac{dr}{r}, \qquad (\iota)$$

integrating which,

$$h = -R \log_\epsilon r + c,$$

and the constant is determined by the surface elements $h = 0$, $r = r_0$, whence

$$h = R \log_\epsilon \frac{r_0}{r},$$

or

$$r = r_0 \varepsilon^{-\frac{h}{R}} = r_0 \varepsilon^{-\frac{\pi h}{L}}.$$

where L is the *half* length.

Substituting for δr in terms of δh in equation (ε), we have

$$nz = -\frac{r^2}{R} \delta h + R\delta h = \frac{R^2 - r^2}{R} \delta h,$$

$$= R . \delta \mathfrak{h}, \text{ obviously,}$$

where $\delta\mathfrak{h}$ is the increment of head in still water corresponding to δh in the wave motion.

Trochoidal subsurfaces then completely fulfil the conditions, provided the orbit radii at successive depths follow the law

$$r = r_0 \varepsilon^{-\frac{\pi h}{L}},$$

h being the depth of the line of orbit centres below that of the surface; or the disturbance due to the wave passage diminishes in geometrical progression while the depth increases in arithmetical progression.

The following table illustrates the above law, and shows how rapidly the disturbance diminishes below the surface.

DISTURBANCE AT DIFFERENT DEPTHS.

Depth in Wave Lengths.	Disturbance.	Depth in Wave Lengths.	Disturbance.	Depth in Wave Lengths.	Disturbance.
Surface.	1.0000	·5	.0432	2.5	.00000015
.05	·7304	.6	.0231	3.0	.0000000065
.1	·5335	·7	.0123	4.0	12th decimal.
·15	·3897	.8	.0066	5.0	15th "
.2	.2846	.9	.0035		
·25	.2079	1.0	.0019		
·3	.1518	1.1	.0010		
·35	.1109	1.2	.00053		
·4	.0810	1.5	.00008		
·45	.0592	2.0	.0000035		

We have then succeeded in finding a mathematical scheme of motion fulfilling the first three conditions, and it only remains to develop the qualities of the motion, and finally to apply the somewhat complex conditions of formation as far as we understand them, in order to discover the initial circumstances necessary for the generation of such motion, and see how far they obtain in nature.

The body of water under the trochoidal surface profile divides itself into an indefinite number of trochoidal subsurfaces of uniform pressure, and since the energy of each particle in a subsurface is the same, they must originally have formed a horizontal subsurface in still water at the corresponding level, or the originally horizontal layers have by the passage of the wave system become trochoidal surfaces. Also the originally vertical layers have become distorted according to the law of the orbit radii. Thus, if we join successive points P, P', etc., originally in the vertical OO', the curve so formed has for its equation in coordinates making an angle θ with one another,

$$r = r_0 \varepsilon^{-\frac{\pi h}{L}}.$$

The equation of the tangent at any point P', $(r'h')$, is

$$(r-r')=\left(\frac{dr}{dh}\right)_{(r'h')}(h-h')$$
$$=-\frac{\pi r'}{L}(h-h')$$

and the point where it meets the vertical OO', obtained by putting $r=0$, is given by

$$\frac{L}{\pi}=R=h-h',$$

or the tangent at P' meets OO' at a point N'' distant R below O'. The logarithmic curve of the distorted vertical layers is thus a "curve of pursuit," the point pursued being at a distance R below the orbit centre of the pursuing point.

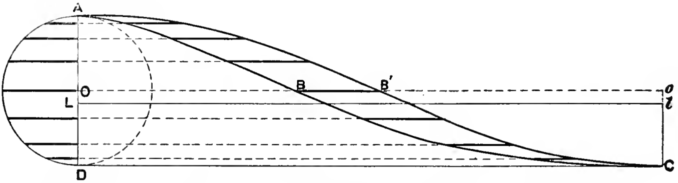
Calling the length $P'N''=n'$ and the angle $P'N''O=\varphi'$, we notice that the triangle $P'O'N''$, n, and φ' for the vertical layers, pass through the same phases as the triangle $P'O'N'$, n, and φ for the horizontal layers, but at different times.

Imagine a perfectly flexible and extensible sheet of some substance of the same specific gravity as water, and originally horizontal at any depth; then, on the passage of the wave, the sheet will conform to the shape of the corresponding subsurface, each element of the length oscillating through the angles assumed by its corresponding line of virtual gravity. Similarly if the sheet be placed originally vertical it will conform to the logarithmic curves, and each element of its length will oscillate through the same angle as when placed horizontally at the corresponding depth, but occupies any given angular position at different times.

Thus a *rigid* stabilized *particle* possessing a small finite lateral but infinitesimal vertical extension, such as a little raft A floating at the surface, will follow the form of the surface, while a similar particle possessing small finite vertical but infinitesimal lateral extension such as a little pole B will follow the form of the distorted vertical columns, oscillating through the same arcs as A but at different times. If we rigidly unite the two, the motion of the new particle will not be exactly the resultant of the two motions on account of the disturbance of the fluid caused by the rigid connection, but in its general nature it will approximate to it. As n measures the force tending to bring the stabilized log A back to the wave form if slightly disturbed from it, so n' measures the force tending to bring an identical pole B, equally stabilized, back to the wave column if disturbed from it.

These considerations, besides illustrating the dynamical structure of the wave, play an important part in the investigation of the rolling of a ship, a rigid floating body possessing both lateral and vertical extension.

Still Water Levels.—A notable feature of the deep water wave is that it is more peaked at crest than at trough. Thus while $AB'C$ represents the harmonic curve or curve of sines or of versed sines, as it is variously called, the crest and trough of which are perfectly symmetrical, ABC denotes the trochoid of same length and height.



Considering the area of half the advancing heap of water $ABCD$, it follows that the corresponding surface of still water must fall below the mid-height Oo, the amount of the difference of level being most simply obtained by comparing the corresponding horizontal elements of the areas of the curve of sines and of the trochoid. The difference at each height is seen to be the corresponding horizontal element of the orbit semicircle, so that the difference in the areas from crest to trough is equal to the area of this semicircle. But the area of the curve of sines, from its symmetry, is the half-product of its length by its height or rL. Whence area of trochoidal half-wave $= rL - \frac{1}{2}\pi r^2$. The corresponding level of still water is therefore the line Ll such that the area of the rectangle $LlCD = rL - \frac{1}{2}\pi r^2$, whence

$$LD = r - \tfrac{1}{2}\pi\frac{r^2}{L}$$

and
$$OL = \tfrac{1}{2}\pi\frac{r^2}{L} = \frac{\pi r^2}{\lambda} = \frac{r^2}{2R}.$$

Thus the mean elevation of the surface particles, throughout the half-wave length, above their corresponding still water level is $\dfrac{r^2}{2R}$.

Energy of the Wave.—It follows that the mean potential energy of each particle in a complete revolution is $mg\dfrac{r^2}{2R}$. Its kinetic energy in its orbit is $\dfrac{m\omega^2 r^2}{2} = mg\dfrac{r^2}{2R}$, the same as its potential energy.

Accordingly the whole energy of the wave is half kinetic and half potential.

Considering any elementary layer $L.\delta\mathfrak{h}$ of undisturbed water, its centre of gravity is by the passage of the wave-form raised through a height $\frac{r^2}{2R}$. This appears immediately from the above, and is also capable of rigid mathematical *a priori* proof. The potential energy of this element is, taking areas to represent weights,

$$L\delta\mathfrak{h}\frac{r^2}{2R} = L\frac{r_0^2}{2R}\varepsilon^{-\frac{2h}{R}}\delta\mathfrak{h},$$

by substituting for r in terms of r_0 and h. But

$$nz = \frac{R^2 - r^2}{R}\delta h = R\delta\mathfrak{h},$$

whence

$$\delta\mathfrak{h} = \left(1 - \frac{r^2}{R^2}\right)\delta h.$$

Substituting and integrating vertically downwards, we have potential energy of half-wave length = kinetic energy of ditto

$$= \frac{Lr_0^2}{2R}\int_0^\infty\left(1 - \frac{r^2}{R^2}\right)\varepsilon^{-\frac{2h}{R}}\delta h$$

$$= \frac{Lr_0^2}{2R}\int_0^\infty\left(1 - \frac{r_0^2}{R^2}\varepsilon^{-\frac{2h}{R}}\right)\varepsilon^{-\frac{2h}{R}}\delta h$$

$$= \frac{Lr_0^2}{2R}\left(\frac{R}{2} - \frac{r_0^2}{R^2}\cdot\frac{R}{4}\right)$$

$$= \frac{Lr_0^2}{4}\left(1 - \frac{r_0^2}{2R^2}\right)$$

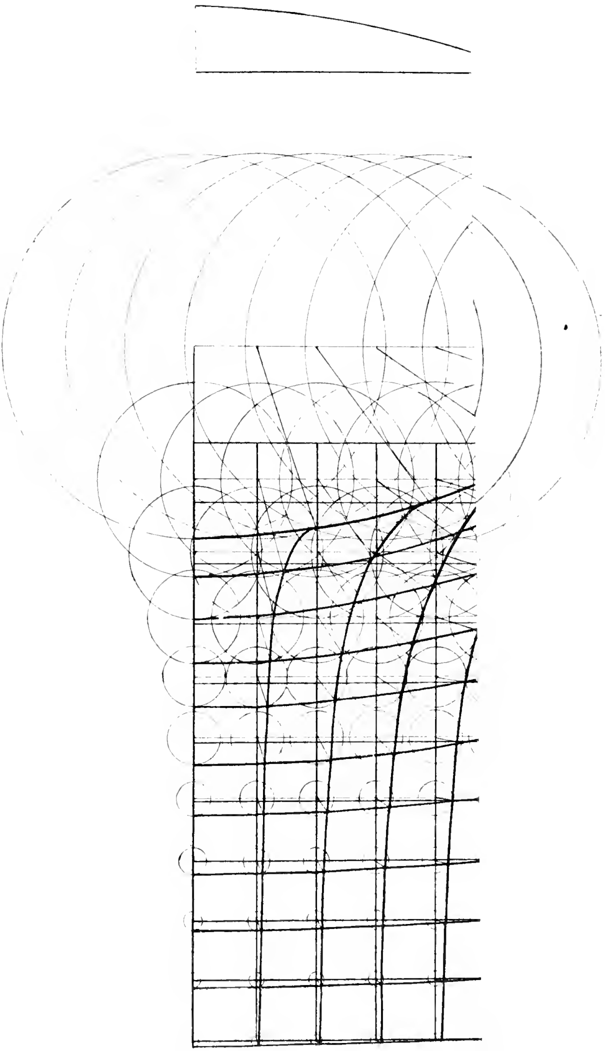
$$= \frac{LH^2}{16}\left(1 - \frac{\pi^2H^2}{8L^2}\right).$$

In ordinary waves $\frac{H}{2L}$ is small, varying from 0.16 for waves of several yards in length to 0.052 for waves of 280 feet half length observed by Dr. Scoresby. For a value of $\frac{H}{L} = \frac{1}{10}$, the above expression becomes

$$= \frac{LH^2}{16}(1 - .01235)$$

in which the decimal is practically negligible.

Thus we may write with sufficient accuracy total energy of wave $= \frac{\lambda H^2}{8}$, which is equal to the energy of the containing rectangle raised through $\frac{1}{8}$ its height. A storm wave 600 ft. long and 30 ft.

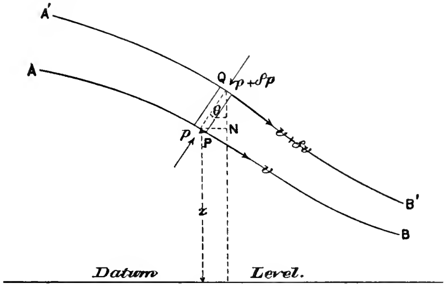


high possesses an energy of nearly 2000 foot-tons per one foot of breadth.

Description of Diagram.

Wave Structure.—The internal structure of the trochoidal wave is graphically shown in the diagram accompanying the paper. The original horizontal and vertical layers are drawn to intersect, so as to form squares, the displacements and distortions of which, with constant area, are shown by the quasi-parallelograms included between the trochoidal surfaces and subsurfaces and the logarithmic curves. The curve above shows the variation of virtual gravity about the ordinary gravity—as represented by the radius of the cycloidal orbit—for the second subsurface. The elevation of the lines of orbit centres above the corresponding levels will be plainly seen, as well as the very rapid increase of this elevation near the surface.

Conditions of Formation—Molecular Rotation.—In stream line motion, consider the equilibrium of a small cylinder, of lateral extension of the second order, described about PQ as axis. P being a point on the stream line AB, and Q on the adjacent stream line $A'B'$. It is acted on by gravity, the pressures on its ends, and the pressure on



the curved surface, the latter balancing to the third order. Along the stream line AB, the head must be constant, or

$$\mathfrak{h} = \frac{v^2}{2g} + \frac{p}{w} + z = \text{constant}.$$

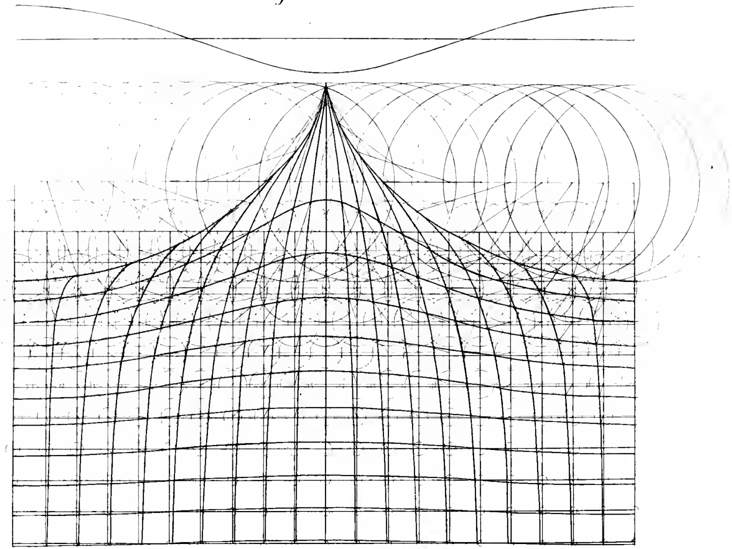
Passing normally across the stream line to $A'B'$, the change in the head will be

$$\delta\mathfrak{h} = \frac{v\delta v}{g} + \frac{\delta p}{w} + \delta z,$$

where $\delta z = QN$ for any point Q.

Calling the sectional area of the cylinder a, and resolving along the axis PQ, we have for equilibrium $w \,.\, PQ \,.\, a \cos\theta + a\delta p =$ accel-

Structure of Trochoidal Wave.



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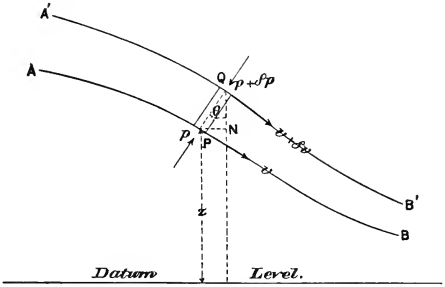
Conditions of Formation—Molecular Rotation.—In stream line motion, consider the equilibrium of a small cylinder, of lateral extension of the second order, described about PQ as axis. P being a point on the stream line AB, and Q on the adjacent stream line $A'B'$. It is acted on by gravity, the pressures on its ends, and the pressure on the curved surface, the latter balancing to the third order. Along the stream line AB, the head must be constant, or



$$\mathfrak{h} = \frac{v^2}{2g} + \frac{p}{w} + z = \text{constant.}$$

Passing normally across the stream line to $A'B'$, the change in the head will be

$$\delta\mathfrak{h} = \frac{v\delta v}{g} + \frac{\delta p}{w} + \delta z,$$

where $\delta z = QN$ for any point Q.

Calling the sectional area of the cylinder a, and resolving along the axis PQ, we have for equilibrium $w.PQ.a\cos\theta + a\delta p =$ accel-

eration normal to the path $= \frac{v^2}{\rho} \cdot \frac{w \cdot PQ \cdot a}{g}$, ρ being the radius of curvature at the point.

Substituting $QN = \delta z$ for $PQ \cos\theta$, we have

$$\delta z + \frac{\delta p}{w} = \frac{v^2}{g\rho} \cdot PQ.$$

$$\therefore \delta \mathfrak{h} = \frac{v\delta v}{g} + \frac{v^2}{g\rho} \cdot PQ,$$

$$= \frac{v \cdot PQ}{g}\left\{\frac{v}{\rho} + \frac{\delta v}{PQ}\right\}.$$

For any two adjacent stream lines, $\delta\mathfrak{h}$ is constant, and also for continuity $v \cdot PQ = \text{constant}$,
whence we have as an indispensable condition for steady motion,

$$\frac{v}{\rho} + \frac{\delta v}{PQ} = \text{constant}.$$

Now evidently $\frac{v}{\rho}$ is the angular velocity of the radius of curvature at the point, and $\frac{\delta v}{PQ}$ is that of PQ, and the above condition expresses the fact that while the angular velocity of PQ may not be the same as that of the normal, yet the sum of the two is constant all along the stream. It is only in a forced vortex that $\frac{dv}{PQ} = \frac{v}{\rho}$, or each particle moves as if rigidly attached to its radius.

The mean angular velocity of PQ and the normal, which is obviously that of the little solidified sphere (or cylinder in motion in two dimensions) previously considered, is

$$A = \tfrac{1}{2}\left(\frac{v}{\rho} + \frac{\delta v}{PQ}\right)$$

and is called the molecular rotation at the point. As we have seen, and it may be shown analytically, its value must be constant along an elementary stream.

Molecular Rotation in the Trochoidal Wave.—For datum let us take the still water level corresponding to a stream line in the steady motion, since the pressure is the same for the two. Then

$$\mathfrak{h} = z + \frac{v^2}{2g} = \frac{r^2}{2R} + r\cos\theta + \frac{n^2\omega^2}{2g},$$

$$= \frac{r^2}{2R} + r\cos\theta - \frac{rR\omega^2}{g}\cos\theta + \frac{r^2 + R^2\omega^2}{2g};$$

or, since $\omega^2 = \frac{g}{R}$,

$$\mathfrak{h} = \frac{r^2}{R} + \frac{R^2\omega^2}{2g},$$

a result which might have been derived from *a priori* considerations of the energy of a particle in the steady motion. Since all layers of still water have the same energy, the above equation holds for layers at all depths, r having the corresponding value. Hence passing from one layer to another,

$$\delta \mathfrak{h} = \frac{2r\,\delta r}{R},$$

which shows that the motion must be rotational.

We have $$\delta \mathfrak{h} = 2A . \frac{V . PQ}{g},$$
where A is the molecular rotation.

Therefore $$A = \frac{rdr}{R} . \frac{g}{V . PQ}.$$

Substituting for $V . PQ$ its value

$$\omega n . PQ = \omega nz = \omega \frac{R^2 - r^2}{R} \delta h,$$

$$= - \omega \frac{R^2 - r^2}{r} \delta r,$$

we have $$A = - g \frac{r^2}{R\omega (R^2 - r^2)},$$

$$= - \omega \frac{r^2}{R^2 - r^2},$$

on substituting for g its value $R\omega^2$. Thus the value of the molecular rotation increases from the bottom up, at a rate increasing very rapidly near the surface.

The trochoidal wave then involves molecular rotation in the manner and to the extent shown above. But if such a wave be formed, and then by the reverse action of natural forces be reduced to still water, the molecular rotation must remain constant.

Thus, suppose the surface of the wave, in the steady motion, to be covered with a *perfectly smooth* film, acted on by such forces as to gradually reduce the water to a level surface. Since the molecular rotation remains unchanged, the water at the surface must now move faster than that beneath it. Thus if U be the velocity at any depth $\mathfrak{h}$, we must have

$$\frac{dU}{d\mathfrak{h}} = 2A = - \frac{2\omega r^2}{R^2 - r^2},$$

or $$\delta U = - \frac{2\omega r^2}{R^2 - r^2} \delta \mathfrak{h} = - \frac{2\omega r^2}{R^2} \delta h,$$

$$= 2 \frac{\omega r}{R} \delta r$$

and, on integrating

$$U = \frac{\omega r^2}{R} + \text{constant.}$$

When $r = 0$, or at a great depth, U must become equal to V, the speed of the wave, whence

$$U = V\left(1 + \frac{r^2}{R^2}\right)$$

Now reducing the steady motion to wave, the lower portions of the water are at rest, while at any depth the velocity is

$$U - V = V\frac{r^2}{R^2}$$

in a direction opposite to that of wave propagation.

In the generation of waves in water at rest, the action of the wind undoubtedly exerts a forward force on the water at the surface imparting a forward momentum to it, which by any lack of fluidity in the water is imparted gradually, at a rate diminishing with the depth, to the water beneath. A current is thus generated somewhat of the nature required by the trochoidal motion, but in the opposite direction.

It is a matter of common experience that extensive surface currents are produced by storm winds. Thus it is related that a difference of level of three feet was observed in the lake of Garda during a severe storm, and during the winter of '72–'73, the Danish Islands were submerged while some Swedish ports to windward were blown dry, the difference of level between the windward and leeward shores of the Western Baltic being estimated at from 9 to 11 feet. All this must have been caused by a large translatory current. In more open and deeper water there would probably be less difference of level, for there the undercurrent of replacement, due to statical pressure, would be less interfered with, giving rise to a very elongated vortex in a vertical plane.

From all these considerations it does not seem probable that a truly trochoidal wave is ever formed except in accidental cases, and yet the modifications rendered necessary by the above, though important in character, are not so important in extent. In general it may be said that there seems to be a marked tendency for waves once formed to *work down* into the trochoidal form and characteristics.

Prof. Stokes has published in the Cambridge Transactions for '42 and '50 a mathematical investigation of quasi-trochoidal motion generated from water at rest, *i. e.* not involving molecular rotation. According

to this theory, the particles describe circles about centres moving forward with the proper velocity $V\frac{r^2}{R^2}$, the motion of oscillation being thus combined with a slow motion of translation, accompanying which is a slight deviation from the truly trochoidal form, the actual wave falling a little within the trochoid of same height and length. The deviation for a wave of height $\frac{1}{10}$ the length is 2 per cent., and varies as the cube of the height. The limiting form is a blunt topped cusp with slope believed to be 30°. There is a small change in the speed of propagation, which is slightly greater by a quantity depending on the square of the wave height.

Although this motion is of some theoretical importance, and may be a trifle nearer the truth than the trochoidal theory, it is still so much more complicated of expression and involves so small a departure from the simpler theory in most cases, that it has not been adopted as a working hypothesis.

Meanwhile actual reliable observations of wave systems are always of value both as a test of theory and an expression of fact.

APPENDIX.

*The General Equation of Continuity in Steady Motion.**—Considering the motion as cylindrical, *i. e.* as propagated in vertical planes, and fixing our attention on a small rectangle fixed in space within the fluid, we have to express the fact that the increase of mass within the rectangle, in any small interval of time, is due to the excess of the mass of fluid which has entered over that which has passed out.

Let x, y be the coordinates of one angular point P, and $x+a$, $y+\beta$ those of the opposite angular point. Then ρ being the density, and u and v the component velocities at P parallel to x and y respectively, the quantity of fluid entering the rectangle by the side β passing through P in time δt will be

$$\rho . u . \beta . \delta t,$$

and therefore the quantity which, during the same time, flows out at the opposite face will be

$$\left\{ \rho . u + \frac{d(\rho . u)}{dx} . a \right\} \beta . \delta t,$$

and the consequent loss due to motion parallel to x is

$$\frac{d(\rho . u)}{dx} . a\beta . \delta t.$$

Similarly the quantity lost in consequence of the motion parallel to y is

$$\frac{d(\rho . v)}{dy} . a\beta . \delta t,$$

* See Besant's Hydromechanics.

and the total loss by flow is

$$\left\{\frac{d(\rho . u)}{dx}+\frac{d(\rho . v)}{dy}\right\}\alpha\beta . \delta t.$$

But the increase in the mass of the fluid within the rectangle in time δt is given by the expression

$$\alpha\beta . \frac{d\rho}{dt} . \delta t,$$

or, expressed as loss,

$$-\alpha\beta . \frac{d\rho}{dt} . \delta t.$$

Equating these losses, we have

$$\frac{d\rho}{dt}+\frac{d(\rho . u)}{dx}+\frac{d(\rho . v)}{dy}=0,$$

the differential expression of the continuity of the fluid in its motion.

If the fluid be homogeneous and incompressible, as in the case of water, ρ is constant, and the equation of continuity becomes

$$\frac{du}{dx}+\frac{dv}{dy}=0.$$

Differential Expression of the Condition of Dynamical Equilibrium.—By d'Alembert's principle, the effective force acting on each particle to produce acceleration is the resultant of its weight and the pressure of the surrounding fluid. Thus, if u, v be the component velocities at the point x, y at time t, and P the pressure at the point, then applying d'Alembert's principle to the component forces and accelerations in directions parallel to the axes, we have

$$\frac{dP}{dx}=-\rho\frac{Du}{dt}$$

$$\frac{dP}{dy}=-\rho g-\rho\frac{Dv}{dt}$$

$\frac{Du}{dt}$, $\frac{Dv}{dt}$ being the component accelerations of the particle, and y being measured vertically upwards.

Application of the above Conditions to Deep Water Wave Motion.—As a tentative functional motion, we will assume the orbit to be the ellipse about the centre, in which it will be noticed that the assumption involves not only the form of the orbit but the velocity of the particle at each point of it. Besides being a mathematically simple case of motion, this assumption has several experimental facts to recommend it, viz. (1) the apparently elliptical orbits observed for the shallow water oscillating wave, by Scott Russell, Gerstner and others, and (2) the observed approximate constancy of *period* of the wave on passing gradually from deep to shallow water—both facts consistent with motion of the particle under a central force of constant intensity, which the above assumption implies.

The mathematical expression of the corresponding "steady motion" is

$$\begin{cases} x=Vt-a\sin\omega t, \\ y=-h+b\cos\omega t, \end{cases}$$

the axis of x being the horizontal line of surface orbit centres, positive in the direction of steady flow, and that of y the vertical upwards through the crest;

a the horizontal and b the vertical semi-axes of the ellipse; h and t are the independent variables, and a and b are of necessity functions of h only.

We have then

$$\frac{dx}{dt} = u = V - a\omega \cos \omega t,$$

$$\frac{dy}{dt} = v = -b\omega \sin \omega t,$$

u and v being therefore explicit functions of h and t only.

Hence

$$\frac{Du}{dt} = a\omega^2 \sin \omega t,$$

$$\frac{Dv}{dt} = -b\omega^2 \cos \omega t.$$

For any subsurface, h being constant, we have

$$dP = \frac{dP}{dt}dt = \left\{ \frac{dP}{dx} \cdot \frac{dx}{dt} + \frac{dP}{dy} \cdot \frac{dy}{dt} \right\} dt,$$

which, in order to satisfy the equations of dynamical equilibrium,

$$\begin{aligned} &= \{ -\rho a\omega^2 \sin \omega t\,(V - a\omega \cos \omega t) \\ &\quad + \rho b\omega \sin \omega t\,(g - b\omega^2 \cos \omega t) \} dt \\ &= 0, \text{ for all values of } t, \end{aligned}$$

on the supposition that the pressure is constant all along the subsurface.

Equating to zero the coefficients of $\sin \omega t$ and $\sin \omega t \cos \omega t$, we have

$$gb - aV\omega = 0,$$

$$a^2 - b^2 = 0,$$

or

$$a = b = r \text{ (say)},$$

$$V\omega = g,$$

or the ellipse must be a circle, and the velocity of the wave must be given by

$$V = \frac{g}{\omega},$$

in order that the condition of dynamical equilibrium may be fulfilled.

The equation of continuity is

$$\frac{du}{dx} + \frac{dv}{dy} = 0.$$

From the above,

$$\begin{aligned} \frac{du}{dx} &= \frac{du}{dt} \cdot \frac{dt}{dx} + \frac{du}{dh} \cdot \frac{dh}{dx} \\ &= a\omega^2 \sin \omega t \,.\, \frac{dt}{dx} - \omega \frac{da}{dh} \cdot \cos \omega t \,.\, \frac{dh}{dx}. \end{aligned}$$

Similarly

$$\frac{dv}{dy} = -b\omega^2 \cos \omega t \,.\, \frac{dt}{dy} - \omega \sin \omega t \frac{db}{dh} \cdot \frac{dh}{dy}.$$

The equations for change of independent variables from h and t to x and y are

$$\frac{dh}{dh} = 1 = \frac{dh}{dx} \cdot \frac{dx}{dh} + \frac{dh}{dy} \cdot \frac{dy}{dh},$$

$$\frac{dh}{dt} = 0 = \frac{dh}{dx} \cdot \frac{dx}{dt} + \frac{dh}{dy} \cdot \frac{dy}{dt},$$

$$\frac{dt}{dh} = 0 = \frac{dt}{dx} \cdot \frac{dx}{dh} + \frac{dt}{dy} \cdot \frac{dy}{dh},$$

$$\frac{dt}{dt} = 1 = \frac{dt}{dx} \cdot \frac{dx}{dt} + \frac{dt}{dy} \cdot \frac{dy}{dt},$$

whence calling
$$\frac{dy}{dh} \cdot \frac{dx}{dt} - \frac{dx}{dh} \cdot \frac{dy}{dt} = Q,$$

we have
$$\frac{dh}{dx} = -\frac{1}{Q} \cdot \frac{dy}{dt},$$
$$\frac{dh}{dy} = \frac{1}{Q} \cdot \frac{dx}{dt},$$
$$\frac{dt}{dx} = \frac{1}{Q} \cdot \frac{dy}{dh},$$
$$\frac{dt}{dy} = -\frac{1}{Q} \cdot \frac{dx}{dh},$$

whence
$$\begin{aligned}\frac{du}{dx} + \frac{dv}{dy} = & \frac{1}{Q}\left\{ a\omega^2 \sin \omega t \left(\cos \omega t \frac{db}{dh} - 1 \right) \right. \\ & - 2b\omega^2 \frac{da}{dh} \sin \omega t \cos \omega t \\ & \left. - \omega \sin \omega t \frac{db}{dh} (V - a\omega \cos \omega t) \right\} \\ = & -\frac{1}{Q}\left\{ \left(a\omega^2 + V\omega \frac{db}{dh} \right) \sin \omega t \right. \\ & \left. + 2\omega^2 \left(b \frac{da}{dh} - a \frac{db}{dh} \right) \sin \omega t \cos \omega t \right\} \\ = & \ 0.\end{aligned}$$

Equating to zero the coefficients of $\sin \omega t$ and $\sin \omega t \cos \omega t$, we have
$$a\omega + V\frac{db}{dh} = 0,$$
$$b\frac{da}{dh} - a\frac{db}{dh} = 0.$$

From the second of these, since a and b are functions of h only, we obtain the relation
$$\frac{b}{a} = \text{constant},$$
which shows that the circular orbit is not imposed by the condition of continuity, but by that of dynamical equilibrium.

Since $a = b = r$ by the latter condition, the above equations become
$$a = b = r,$$
$$V\frac{dr}{dh} + r\omega = 0,$$

whence
$$r = r_0 \varepsilon^{-\frac{\omega h}{V}} = r_0 \varepsilon^{-\frac{\omega^2 h}{g}}.$$

Thus the assumed mathematical motion satisfies the first three conditions of the deep water wave motion, provided the elements of the motion fulfil the relations
$$a = b = r,$$
$$V\omega = g,$$
$$r = r_0 \varepsilon^{-\frac{\omega^2 h}{g}}.$$

DISCUSSION.

THE CHAIRMAN.—I have been much interested in listening to Mr. Gatewood's paper on his mathematical explanation of the trochoidal wave motion. I do not intend discussing his scheme of motion of deep-sea waves, except to say that it is evidently the theory of the true or perfect wave, but this wave is not often met with.

I regret that I cannot add something practical from my own observations. For four years, while attached to the U. S. Coast Survey, I was employed investigating the physical features of the deep-sea; its depths, currents, density, temperatures, &c. I had planned taking observations of waves, not only to add to the general science of the ocean, but also the relation of their curves, &c., to the construction of our ships.

My spirit was always willing but my flesh was weak, as whenever I met waves of any magnitude in the little steamer Blake of only 300 tons, my one idea was to get out of them into smooth water. Most of my work has been in the Gulf Stream, and any of you that have seen waves there will agree with me that they are too bad to investigate. It would be necessary to get up very peculiar curves for waves formed there by a sudden NE. gale against a current of three or four knots an hour. The subject is a very interesting one, and as all physical inquiry of the ocean strictly comes under the sphere of the Hydrographic Office, I hope to see forms, with proper instructions, sent to our vessels to be filled out when at sea and sent to the Department each quarter. With a long vessel, the distances between the crests of waves can certainly be measured. I trust we may have some of this data to present to you before the end of another year.

PASSED ASSISTANT ENGINEER J. C. KAFER.—The paper just read is not one that can be fully discussed after hearing it for the first time, but will require careful study from those desiring a knowledge of the subject.

The angles of roll determined from the observations of the swinging of a pendulum are of no practical use; and, in order that we can find out how much our ships roll in a sea-way, I would suggest that the angles of roll should be taken by sighting the horizon over a batten, as is now done in the English and French navies.

ASSISTANT NAVAL CONSTRUCTOR F. T. BOWLES.—This paper presents material for careful and useful study; and although it includes only the simple fundamental case of wave motion, it will require frequent reference to more popular and geometrical treatises to master the subject. The trochoidal wave system is taken up from a purely mathematical standpoint, and as such is shown in the paper to completely satisfy the conditions.

The paper shows, through consideration of molecular rotation, that by natural causes, apart from friction, a purely trochoidal wave cannot be generated from water at rest, and hence the existence of a purely trochoidal wave is accidental.

It is found, however, that the trochoidal agrees substantially with wave phenomena, provided their heights do not exceed $\frac{1}{10}$ of the length. This is much higher than the average wave, which is about $\frac{1}{25}$ of the length.

We find nothing in the general theory to connect the height of the waves with length, velocity or period, and we find that our actual knowledge of the formation of waves is very vague.

M. Bertin in his paper before the Institute of Naval Architects, 1873, urges the frequent observation of the wave phenomena, saying that observation must precede science in these investigations.

Information of great value could be collected by our ships in this respect, and with that view I would suggest that there be annexed to this paper a copy of the memorandum prepared by Mr. Wm. Froude, to assist officers in observing at sea the heights, lengths and velocities of waves.

If a regular series of waves be met with at sea while either sailing or steaming, an account of the behavior of the ship, that is, the time and amplitude of oscillation, and the circumstances, viz. the relative position to the waves, their length, height and velocity, the wind in force and direction, would form very instructive and useful information. By means of such data a naval architect can obtain from considerations of the effective wave slope and comparison of the experiences of different ships, definite and reliable data as to effect of the proportions of ships as to steadiness for gun platforms. The mention of this reminds me that we have at present a report of sailing qualities, made quarterly, from each ship to the Bureau of Construction and Repair ; this might and should be the means of conveying valuable information and data of great interest to a naval architect.

The present report is of an entirely obsolete character, and contains very little, if any, useful information.

It is difficult in discussion to avoid wandering from the matter in hand to that which is to follow on the rolling of ships. But in regard to the effect of the decrease in virtual gravity upon vessels upon the crest of waves I think Mr. Gatewood understated the results of experiments by Captain Mottez, who found that the apparent weights of objects were in the ratio of 8 to 12 when the vessel was upon a crest and in the trough of wave, and as a remarkable confirmation of this I may remind you that instances have been recorded of vessels coming into harbor under sail and capsizing instantly upon passing the crest of a large wave raised upon a bar by a swift tide and opposing wind.

This is due to the fact that the righting moment of statical stability is decreased in the direct ratio of the virtual gravity.

Commander C. M. Chester.—I agree with Mr. Kafer that the paper, so ably presented to us to-night, treating of the subject of deep-sea waves, is not one to be lightly discussed, but when published will bear close study, with profit to those who undertake it, and in this connection I want to second the suggestion of Mr. Bowles, that Mr. Gatewood would append to it in the Proceedings of the Institute the article by Mr. Froude on measurements of waves, or still better, to prepare a paper adapted to practical men whose knowledge of the subject is less than that of those who composed Mr. Froude's audience.

The two combined would form a text-book for use, which, as formulated by the lecturer for Mr. White's book, should be in the hands of every naval officer. I have felt the need of such a book this very day. It occurred to me that one of our vessels in the Coast Survey, which is engaged on current work, might, while at anchor in deep water off our coast (it is hoped she may succeed in occupying stations in depths up to 1000 fathoms), be able to obtain some valuable results, but I found myself at a loss to know how to direct the work; I could not copy the long article which White devotes to it, neither could I send the book itself. The monograph suggested would not only be useful to us as seamen, but would be "bread cast upon the waters" for the constructors themselves. Many officers, after once being interested, would, I am sure, carry the study to as successful an issue as can be done by the officers of any other service, and many records collated and edited in the office would benefit us all, both in *personnel* and *materiel.*

PASSED ASSISTANT ENGINEER J. C. KAFER.—What estimate was made of the heights of the waves in the experiments mentioned by Mr. Bowles?

ASSISTANT NAVAL CONSTRUCTOR F. T. BOWLES.—I cannot give any actual heights of the waves, but may mention the results of experiments by Captain Mottez, that the ratio of weights, as indicated by a spring balance, was 12 to 8 when in trough and on crest of a wave, thus indicating a range of 40 per cent. in the actual weight, and hence in the righting moment.

PASSED ASSISTANT ENGINEER J. C. KAFER.—Then, I think, there is something else than actual weight—it may be inertia of the water, not its position on the surface of the globe.

ASSISTANT NAVAL CONSTRUCTOR F. T. BOWLES.—No, it is the acceleration of wave water—not the absolute distance from the centre of the earth.

PASSED ASSISTANT ENGINEER J. C. KAFER.—I only wanted that to be made clear.

NAVAL CONSTRUCTOR S. H. POOK.—Many years ago, while I was designing merchant ships, I wrote and sent out a circular calling for information similar to that just mentioned by Mr. Gatewood, but I am sorry to say that I received no answers. Gentlemen who are in command of ships will seldom take the trouble to obtain the information of which naval architects are so much in need, that is, to report all the qualities and performances of their ships at sea.

It is very desirable to have a circular sent out, and it is to be hoped that it will be attended to and issued as soon as possible.

We are constantly planning improvements in our ships, but we need many facts yet to avoid mistakes, and make our forms correspond with true science.

Now there seems to be one way in which this information can be obtained: after determining upon a proper circular, to make it the special duty of one officer on each ship to collect all the information he can of the behavior and qualities of that particular ship in accordance with the forms given. To do

this well, however, he needs instruments to correspond with the work he has to perform, as well as a perfect knowledge of their uses, and no other sea duty which will interfere with this one.

Commander C. M. Chester.—It is very desirable, as mentioned by Mr. Pook, to have some special officer on board ship to carry on the work, but if we wait until an officer is detailed for this duty alone I am afraid we will never get it. I think the only safe way is for each officer to devote as much time and attention to it as he can, thereby working up an interest in the subject throughout the service, when, perhaps, a particular person might be assigned for this duty. There are very few of us who cannot spare an hour each day for experimental data, and out of the whole record, procured by such a scheme, there must be found some useful results which the Bureau of Construction might utilize in designing ships.

Assistant Naval Constructor R. Gatewood.—I will take the liberty of replying to the remarks in the inverse order in which they have been made.

As to the observations to be taken aboard ship on the waves and consequent behavior of the ship, there can be no doubt, as suggested by several gentlemen this evening, that the complete system of observations should consist of the elements of the actual waves met with, their effective slope, and the resultant behavior of the ship. Such complete information, however, is not easily obtained under ordinary circumstances, though it has been collected in special cases.

Mr. Froude made such experiments on H. M. S. Devastation both in the Channel and on a voyage to the Mediterranean, and the results form an interesting Parliamentary paper. The apparatus which he used was very beautiful, requiring delicate handling and careful construction, but it need not be very costly. I have myself proposed designing something of the kind and to test it by a series of trials, and if the instrument be made and a few officers instructed in its use, it should thereafter become a service fitting, and be used for systematic observations on all ships in commission, whenever circumstances will permit.

Especially have I proposed something of the kind for the vessels of the Coast Survey, in which service we have a body of gentlemen of very high scientific attainments, devoted to naval science. On naval vessels, officers have active duties, and consequently that of making the necessary observations of the ship's performance should fall to one officer only.

Mr. Froude's genius has put this subject on an assured basis, and almost alone he has explored it deeply. It remains for those devoted to naval science to extend the observations in the direction which he has both indicated and followed out, and such work I believe to be within the capabilities of many of us. Certainly it would add very much to the usefulness of the navy in its own immediate sphere, besides materially advancing this branch of science.

I should have liked very much to continue the paper in the direction of the practical observation of waves, but it is admittedly very incomplete even as

regards the theory of the subject. My main object has been to lay before you the principal features of deep sea wave-motion, so that in future practical work on this subject, those having charge of experiments might understand at least the rudiments.

In such a complicated subject as the motion of a ship, the circumstances of each individual case should be studied, and it must be admitted that a general knowledge of the laws governing such motion on the part of observers would very much enhance the value of their reports.

In regard to the report of sailing qualities, of course, being attached to the Bureau of Construction, I should speak lightly of this subject, yet I cannot but think it very obsolete and worthless. It is only by systematic observation and record that we can obtain accurate information as to a vessel's performance. Vague reports are merely of popular interest, while systematic scientific observations in this direction would, I think, deserve careful record, and, in some cases, publishing as of general scientific value.

Mr. Bowles has mentioned M. Bertin's paper on the systematic observation of waves. On a previous occasion in this room I have spoken of the somewhat remarkable concerted plan of observation recommended by this eminent authority, and it is perhaps scarcely necessary to mention that he divides the globe into sections and quasi-squares, as is the custom with our Hydrographic Office, and recommends observation as to the mean elements of the waves met with in each locality, the circumstances being specified so that we may know the elements of the average wave, say of the Pacific Ocean at various seasons, and the average elements of the storm waves there ; the first as affecting the general performance of ships sailing in that part, and the second as bearing upon their safety.

The Transatlantic lines have been suggested as being a fine field for such observations, but I fear the work would require special attention, because the captain of an ordinary Atlantic liner would scarcely be able to devote the necessary time to making such observations and filling in the forms.

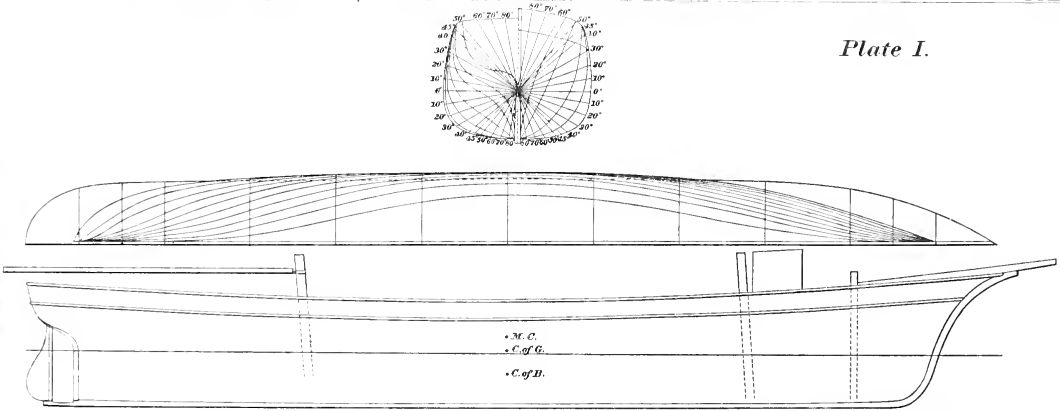
Regarding the accordance of actual with theoretical simple waves, as I have said, observations of simple series under favorable circumstances are still acceptable. It may be remarked, however, that it takes a practiced eye to detect such a series on most occasions. Thus, Wilkes, although on the lookout for them, did not meet such waves until he reached Cape Horn, and some observations made in a *confused sea* off Funchal were discarded on account of great irregularities, as we should naturally expect under the circumstances.

Some remarks have been made as to the inaccuracy of pendulum records, in which I heartily agree. Their error depends upon their proximity to the *point tranquille* or quiescent point, or point of least motion, and is usually large. Batten experiments, or still better a long period pendulum such as previously spoken of in connection with Froude's apparatus, are alone reliable. Wherever placed, the error of a pendulum is always greatest the greater the roll, which being the case of greatest danger is just where we desire most accuracy. Experiments have been made in the French navy to determine this *point tran-*

quille. One observer determined it for his ship as lying between the centre of buoyancy and the water line, and on another ship it was determined as between the centre of buoyancy and the keel, and in both cases it appeared to vary with the stowage. At this point, wherever found, the errors of a pendulum would be a minimum, which fact formed the basis of their experiments.

In reference to the effect of currents in various directions on wave formation, not much is known except as to its general nature, and that it is sometimes very remarkable. The subject is, as far as I know, open to analysis, and the Gulf Stream offers an excellent field, which I hope will not long be unoccupied.

Plate I.



Drawn by Master H. F. Reich, U.S.N.

U. S. C. S. S. Bache.

Scale of Feet.

5 0 5 10 15 20

NAVAL INSTITUTE, WASHINGTON BRANCH.

April 12, 1883.

Asst. Naval Cons. R. Gatewood, U. S. N., in the Chair.

CURVES OF STABILITY.

By Commander C. M. Chester, U. S. N.

The night of September 6th, 1870, was a memorable one in the annals of the British navy. A few days before, the Captain, a large ship of the line, of new design, manned by the elite of the English service, with the designer himself on board, took her place in the Channel squadron, and on that night capsized, and carried with her to the bottom nearly every soul on board. Twice before had she taken her place in the line, to pass through heavier gales than the one experienced on that ill-fated night off Cape Finisterre; the report of each bringing forth encomiums that were fast carrying her name to the head of the list of English war vessels. We who were associating with the naval officers of the mother-country at that time remember what a gloom was cast over their whole service by this sad affair, and yet we can now see that even in this case the old adage, "It is an ill wind that blows nobody good," is not inapplicable.

A scientific commission, comprising among its number some of the most noted men, both civil and naval, in England, demonstrated principles from this calamity of which the naval powers of all Europe were not slow to take advantage. And the object of this paper is to show that we, on this side of the Atlantic, may learn a lesson therefrom that shall, at least, be of interest, notwithstanding our weak claim to naval power; and if, as we trust, there shall be in the future an awakening to the necessity of strengthening our naval force, and ships shall be built, the subject is one which must receive attention.

Curves of stability had been discussed some years before the sad event referred to, but they appeared of so little importance, that not even the peculiar construction of the lost ship had excited sufficient interest to cause one to be produced, until a few days before she sailed on her last fatal trip; not then, in fact, because it was supposed to be really needed; for the meta-centric height of this vessel being greater than that of the Monarch, a vessel which in practice had given excellent results, as well as the fact that the Captain had already made two short but most successful trips, removed all doubts as to her safety.

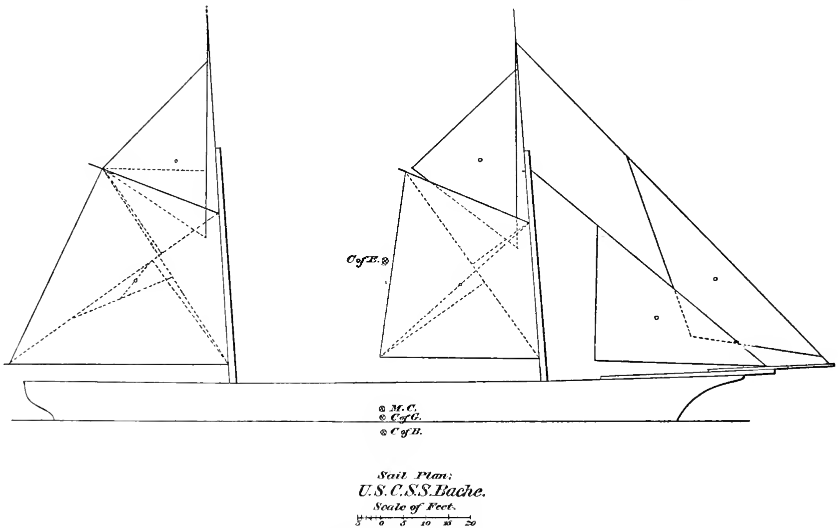
Immediately afterwards the Construction Department of the British navy was taxed to the utmost to produce this curve for nearly all the ironclads of that service; and the author of this method of showing stability, Mr. E. J. Reed, who a short time before had resigned his position as Chief Constructor of the navy, did not forego the usual cry of "I told you so," when the Captain went down. The Captain's curve showed, what is now so apparent to every one, that she was sadly deficient in stability.

It might be well for us to recall a little of this famous vessel's history, as so much of the whole subject of naval architecture is based upon her loss, and particularly so is this question of curves of stability. The Captain, a combination of the turret and casemate system of monitors, was designed by Messrs. Laird and Capt. Coles, and was intended to have about eight feet free board, but, as not unfrequently happens in naval construction, the actual weights placed on board far exceeded those estimated for in her design, bringing the edge of the deck, when loaded, to within six and a half feet of the water.

It is unnecessary to discuss the reasons for the British Admiralty's departing from the usual course and placing her construction in private hands, rather than to have her built at a government yard. At all events the Messrs. Laird were the contractors, and she was built at Birkenhead in 1869, where she remained about a year, when she proceeded to Portsmouth.

The report of this passage was very favorable to her, and from doubting her safety, people began to praise her sea-going qualities, until this praise finally reached a climax just before sailing on her last trip. After a short rest at Portsmouth, she took two sea voyages of about a month each, returning each time with stronger praise from the officers attached to her, and fortified with stronger proof as

Plate II.



Sail Plan;
U.S.C.S.S.Bache.
Scale of Feet.

to her stability. Just before the second trip a second heeling of the ship took place under the direction of the Construction Department of the British navy, the first results performed by the contractors not being entirely satisfactory even to themselves; and on this last experiment is based the curve of stability used in this paper.

It must be remembered that in all these sea trials it was found almost impossible, as reported by Capt. Burgoyne, her commander, to list her more than six degrees, and yet for some unaccountable reason she was, as shown in testimony given in the court-martial ordered upon her loss, sailing with a steady heel of fourteen degrees, only a short time before her last fatal inclination.

This fact tended to silence the strong objections made against low free-board masted ships as far as the Captain was concerned, although they were made with increased vehemence a short time afterwards.

She sailed then on her third and last trip in the height of much excitement caused by her previous good records, and in a few days came the startling news that while quietly proceeding under sail and steam, not on an unusually stormy night, but during an ordinary squall, she suddenly solved the problem upon which the Construction Department was then at work.

Turning completely over, all escape was cut off for the five hundred people on board, with the exception of barely a dozen, who escaped to tell the sad story that so shocked the whole civilized world.

This subject being one of great interest to those who have made it a study, was in my mind on being ordered a few years ago to the United States Coast Survey steamer A. D. Bache, an iron vessel built by the Pusey Jones Company, of Wilmington, Delaware. I found her stability had been questioned to such an extent that during a comparatively light squall, a short time after assuming command, a strong feeling of insecurity had manifested itself among a great many of the crew, not to say some of the officers. So much doubt had existed as to her stability, that the subject was held under discussion for some time before the light upper deck was put on her. This was supposed to have carried the centre of gravity of all weights on board so high as to make her a dangerous vessel. I held that her form gave her a meta-centric height of at least two feet, with which, and her high sides, she was perfectly safe. I determined, however, not only to

satisfy myself, but to endeavor to convince others of the correctness of my opinions the first opportunity that occurred.

It may be well to mention the preliminary steps which had to be taken in this case, for I was unable to obtain the plans from which the vessel was built, and the active work of the survey prevented much attention being paid the subject until just before being transferred to other duty. At this time the vessel, her iron hull beginning to show signs of weakness, was placed in dock for several weeks to receive a sheathing of wood, and an opportunity was thus afforded for obtaining the desired information. Measurements were carefully taken and the plans shown in Plate I were made, from which the first calculations of displacement, centre of buoyancy and meta-centre were obtained.

Soon after (having in the meantime been relieved from the command of the vessel by Lieutenant-Commander E. B. Thomas, U. S. N., who entered with zest into the subject), a favorable opportunity occurred to heel the ship for the purpose of finding her centre of gravity.

It is not my intention to discuss this simple problem and interesting experiment, which all the late works on naval architecture give in detail, but I will just quote the report of the then commanding officer, in his letter to me, dated steamer Bache, Norfolk, Virginia, January 20, 1882.

"The ship being on an even keel, drawing seven feet nine inches forward, and eight feet nine inches aft, the position of a plumb-line twenty feet long was marked, the line being suspended in after-part of forehatch amidships. Another line ten feet long was suspended from the after-part of the engine-room skylight. By moving a weight of 14,899 pounds from amidships to the starboard side of the deck, through a distance of nine feet five inches, the forward line moved through a space of sixteen and a half inches, and the after one eight and three-quarter inches, and by moving the same weights from amidships, through the same distance, to the port side of the deck, the forward line moved through a distance of seventeen inches, and the after line eight and three-quarter inches."

Conditions: "Water in donkey boiler. No water in main boiler. $59\frac{550}{2240}$ tons coal in bunkers. All boats at davits."

A previous letter had given more in detail the conditions under which another experiment was made, but as there was no check on

the results obtained, the data was discarded, and ship again heeled, as noted above.

From this we deduce that the Bache at a mean draught of water of 8.25 feet, displaced 383.5 tons, her centre of buoyancy was 3.18 feet below water line, meta-centre 6.12 feet above centre of buoyancy, and her centre of gravity was 2.34 feet below meta-centre. The last was the important factor of the problem, commonly called the meta-centric height.

For many years this meta-centric height, being coupled with the fact that the centre of gravity was considered to be nearly at the load water line, was assumed to be a satisfactory solution for any question that might arise as to the stability of ships. It may be claimed that this measure of stability is good enough for all practical cases that now can arise, yet it is doubtful if all of us would be satisfied to sail a vessel, whose surplus of stability over the minimum allowance usually conceded to safety, was thirty-four hundredths of a foot, two feet being the minimum.

There are many who remember the croakers who predicted the capsizing of the Congress, Severn, and that class of vessels, after the upper decks had been placed upon them, or, as one of our naval officers stated it, "the topgallant forecastles were extended aft to the break of the poop." Yet I venture to say they had a meta-centric height of at least three and a half feet; and I think the wisdom of building these decks was apparent to all who sailed in them.

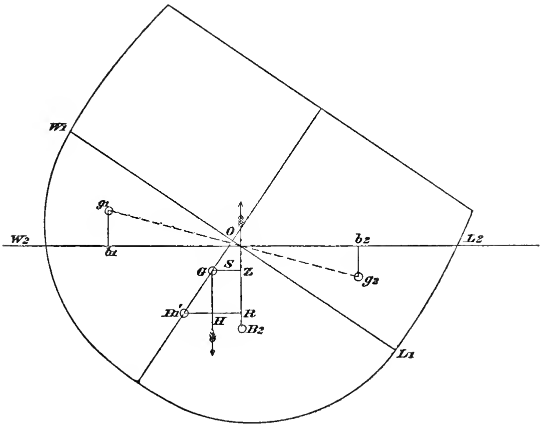
But to our case. The formulas for statical and dynamical stability were worked out many years ago, but they were not of particular utility until a comparatively recent date. The forms that I have taken for this problem of the Bache's stability were those tabulated by Wm. Henry White, Esq., and Wm. John, Esq., and presented before the Institution of Naval Architects, March 30th, 1871, and reported in the volume of Transactions for that year.

"Statical stability" may be defined as the moment of the righting couple of a body, when disturbed from the upright position; and in a ship is equal to its weight multiplied by the horizontal distance through which the centre of buoyancy has been shifted with reference to the centre of gravity.

"Dynamical stability" means the quantity of work done in causing a body to deviate to a certain extent from the position of equilibrium.

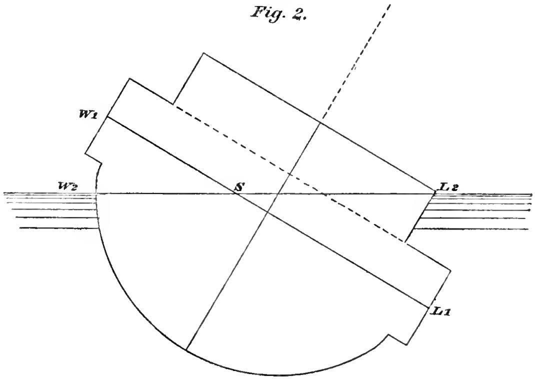
To illustrate this we will refer to Fig. 1, where W_1L_1 represents the upright water line, and W_2L_2 the inclined water line. It is obvious that the volume W_1SW_2, emerged in passing from the

Fig. 1.



upright to the position shown, must equal the volume L_1SL_2 immersed. At first sight it may appear easy to fulfil this condition, but in practice it is not so, particularly when ships have such cross sec-

Fig. 2.



tions as a monitor similar to that shown in Fig. 2, where a portion of the immersed wedge has been cut off by the deck passing under water.

It is possible to always obtain a solution of any required precision by trial and error.

If in heeling around a longitudinal axis passing through the centre of gravity there is a tendency to carry a greater body under water on one side than is raised out on the other (as is usually the case), the axis of revolution must rise during the inclination; for the displacement or weight being the same, and consequently displacing the same amount of water, the body must rise in order to equalize the volume immersed. There is, then (the centre of gravity being a fixed point within the ship), a rise of this axis in heeling, and a fall in righting again.

Supposing that on the contrary, as in the case of the monitor, the heeling would carry a less capacity under water than it would raise out, the same alternate rise and fall would take place, but with opposite signs.

After finding the true water section, which makes the wedges of immersion and emersion equal, we come to find the new centre of buoyancy B_2, Fig. 1, corresponding to the new water line W_2L_2, in order that the *statical* and *dynamical* stability may be calculated.

As was stated for the statical stability we require to know the length of the arm of righting couple, tending to restore the ship to the upright, which is the perpendicular GZ, from the centre of gravity G, upon the vertical line passing through the new centre of buoyancy B_2, and its product by the displacement gives the statical righting moment. For the dynamical stability, however, the depth of B_2, below the water, must be known. That is, the effect of inclining the ship is to transfer the volume of emersion W_1SW_2 to the position of the volume of immersion L_1SL_2, moving the centre of gravity from g_1 to g_2.

In the transfer the movement of the centre of buoyancy from its position B will take place along a line parallel to that joining $g_1\,g_2$, and from mechanics we get—

$$B_1B_2 = \frac{g_1g_2 \times \textit{Volume of wedge}}{\textit{Displacement}} \qquad (1)$$

That is, the distance through which the centre of gravity of a body has been shifted by transposing a given weight, is to the distance

which the centre of gravity of the weight is moved, as the weight is to the body. This motion of the centre of buoyancy can be decomposed into two motions, represented by B_1R, parallel to W_2L_2, and B_2R, perpendicular to it, and as we require B_1R for the statical, and B_2R for the dynamical stability respectively, this is desirable.

We may express this by the equations.

$$D \times B_1R = V \times b_1b_2 \qquad (2)$$

$$D \times B_2R = V(g_1b_1 + g_2b_2) \qquad (3)$$

Now the moment of righting couple (called M) at an angle of inclination θ, is

$$M = D \times GZ$$

From Fig. 1

$$GZ = B_1R - B_1H$$

and

$$B_1H = B_1G \sin \theta$$

Substituting this value of B_1H and from (2) that for B_1R we have

$$\begin{aligned} M &= D\left(\frac{V \times b_1b_2}{D} - B_1G \sin \theta\right) \\ &= V \times b_1b_2 - D \times B_1G \sin \theta \qquad (4) \end{aligned}$$

By mechanics we have the dynamical stability, or the work done is equal to the weight of the body into the distance through which the centre of gravity moves, or

$$U = (B_2Z - B_1G)D$$

and in a similar manner as for statical stability we get

$$\begin{aligned} U &= (g_1b_1 + g_2b_2) - D \times B_2R \\ &= V(g_1b_1 + g_2b_2) - D \times B_1G \text{ ver. sin } \theta \qquad (5) \end{aligned}$$

These and other minor ones for corrections are the formulas then upon which my work is based; and until Mr. Barnes, formerly Chief Constructor of the British navy, brought forth his scheme for utilizing them, their practical solution was of little value to any one.

Let Fig. 3 represent a transverse section of the Bache at load draught.

G the centre of gravity through which the whole weight may be supposed to act downwards.

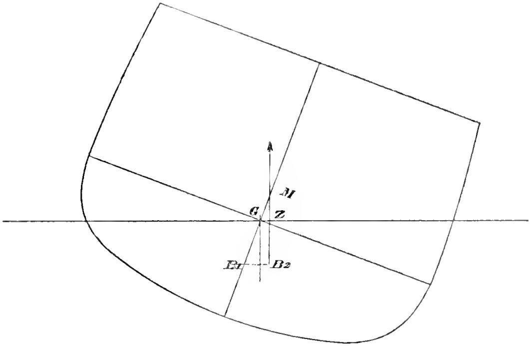
B_1 the centre of buoyancy.

B_2 new centre of buoyancy through which the whole buoyancy, equalling the weight, may be supposed to act upwards.

M meta-centre: then:

GZ by being proportional to the statical stability, or arm of righting couple, may be regarded as the lever which tends to right the ship after she has been heeled.

Fig. 3.



The ship being inclined by some external force, as the wind on the sails, say to 20 degrees, the lever *GZ* will have increased for each angle of heel, and the statical stability will be found in the form of a constant force. The total buoyancy or weight of the ship multiplied by the length of the arm *GZ* tending to push the ship back to the upright position, and consequently the righting force at any instant, will depend upon the length of this arm.

We have shown in general how to find this length depending upon the wedges of immersion and emersion.

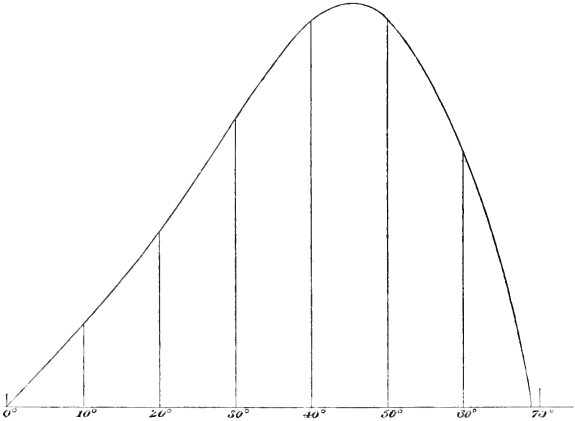
In the case of the Bache:

At 10	degrees	the length	of *GZ*	is	0.65 feet.
20	"	"	"	"	1.16
30	"	"	"	"	1.77
40	"	"	"	"	2.50
50	"	"	"	"	2.64
60	"	"	"	"	1.93
70	"	"	"	"	—0.06

Representing these distances on any convenient scale, say one inch to the foot, and at any distance apart, we have the necessary seven

points for completing the curve satisfactorily, and this is the "curve of stability" required.

Fig. 4.

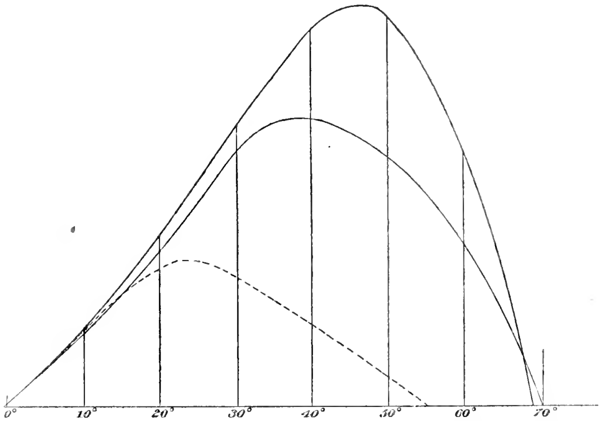


Not much in itself, but a glance at the forms for computations, and remembering that there are two and sometimes three of these for each ten degrees of heel, or about twenty-five in all, will show that considerable time is required for solving the problem. It is for this reason probably that more of them are not used. I am glad to notice, however, that the students of the Royal Naval College have lately been making their education of practical benefit, by obtaining data for the large merchant steamers and producing the curves, and when we realize that in some of these vessels when light the meta-centric height is a minus quantity, they become of much value to their owners.

Plate I shows the manner of preparing the body plan of the Bache for the calculations of the different wedges as the vessel is supposed to heel from 0° to 90°.

For the purpose of comparison, discussion, &c., of the curve, we can take no better example than that of the Captain, as she is an extreme case, and her vanishing angle is not only shown by the curve, but within certain limits is known by actual practice. As a model curve we will combine with it that for the English ironclad Monarch—when the marked difference between them will be at once noticed.

Fig. 5.



First, the righting levers are about the same up to about 21 degrees of heel, when the Captain has reached the maximum length. It then begins to shorten, and disappears at $54\frac{1}{2}$ degrees, the edge of the deck having gone under at 14 degrees.

The Monarch's and Bache's curves, then, proceed nearly together beyond 30 degrees, the former being at a maximum at 40 degrees, her deck beginning to be covered at 28 degrees. The latter still increases till it reaches an angle of heel equal to about 50 degrees and there drops suddenly (the deck having been submerged at 40 degrees) until the vanishing angle is reached at about the same point as the Monarch's, 70 degrees. Until the edge of the Captain's deck has become awash the similarity of the three curves is accounted for by their having nearly the same meta-centric height—

The Captain	2.60 feet.
Monarch	2.37
Bache	2.34

In this connection I would say, however, that the Bache would hardly pass under insurance rules for as high-sided a vessel as the plan would show, and I should prefer to consider the top of the free-board reached at about 30 degrees. Above that the light and numerous ports would not stand much pressure of the water even if securely

closed. This then would cut off the top of her curve and make it almost identical with the Monarch's.

Comparing Figs. 6 and 7, showing the Captain and Monarch both

Fig. 6.

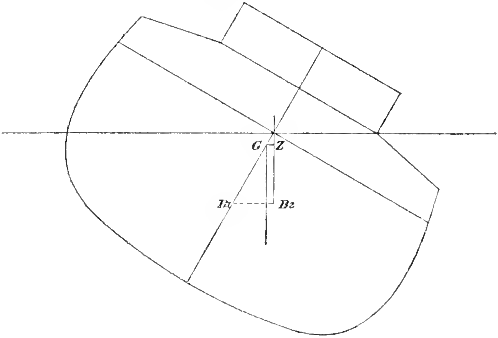
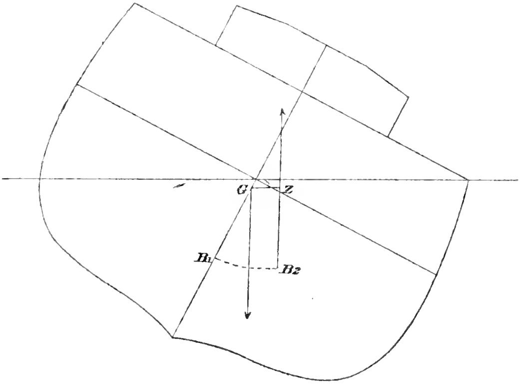


Fig. 7.



heeled to 28 degrees, it will be seen that the Captain's deck has been submerged, and a glance will indicate that there has been a tendency to raise more of the emerged side out of water than was immersed. This tendency has had two results. First, the ship has sunk bodily

into the water in order to preserve the equality between the weight and buoyancy, the buoyancy or immersed volume on the depressed side has diminished instead of increased, and consequently the centre of buoyancy which before moved out has now moved back again towards the centre of the ship, and thus the lever GZ has begun to diminish below what it was at 21 degrees, where it was at a maximum. This decrease goes on to $54\frac{1}{2}$ degrees, where the centre of buoyancy is immediately under the centre of gravity, and the lever arm is gone. The Monarch, on the other hand, has a constant tendency to increase her immersed section, the centre of buoyancy moving out all the time and lengthening the lever arm.

We must remember that in this discussion only the statical stability has been considered, and as we come to the dynamical aspect of the case we will find greater cause for alarm. It is a common way to express the dynamical stability by saying that it is the integral for the expression for statical stability, which may be shown—

or $$U = \int M d\theta.$$

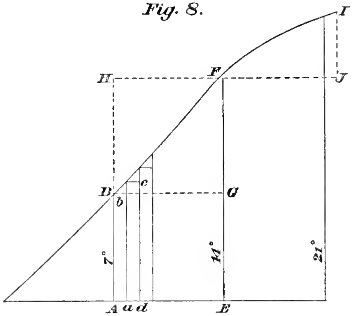
A little illustration as given in Messrs. White and John's paper may make this clear. Suppose a man pushing at the end of a capstan bar, he can balance a *statical* or steady moment equal to the product of the pressure he exerts by the distance he is from the centre of the capstan. Now suppose him to move, keeping a constant pressure as before, the work done by him, corresponding to the dynamical stability, will equal the product of the pressure he exerts into the distance he moves. This distance is proportional to the arc of the circle and the angular distance travelled by the bar, consequently the work done is proportional to the product of the angular interval into the statical moment which the man could balance, hence U equals the product $Md\theta$.

As the statical stability represents a steady force, which as we all know is not usually encountered at sea, we find it necessary now to consider the dynamical aspect. We have seen that the dynamical stability developed during the inclination from one angle of heel to one only infinitesimally greater, is equal to the statical stability into this infinitesimal small space through which it acts, and in a like manner the dynamical stability for any angle will equal the sum of a series of such products.

But the statical stability is proportional to the lever GZ, consequently the dynamical stability will be proportional to that lever into the infinitesmally small space.

To illustrate, let us take the Captain's statical curve, or a portion of it enlarged (Fig. 8). The dynamical stability produced in an inclin-

Fig. 8.



ation from seven degrees to an angle slightly greater, will be equal to *AB* multiplied by this small space, equal evidently to the small rectangle *ABba*. The work done by a still further slight inclination will be equal to the rectangular area *abcd*, and so we may proceed with all the space between *AB* and *EF*. The sum of all the rectangles or the whole area then will represent the dynamical stability from an angle of seven degrees to fourteen degrees. In other words, the dynamical stability during an inclination from one angle to another is represented by the corresponding areas between the angles on curves of statical stability. These areas themselves are sometimes represented as ordinates, and a new or dynamical curve drawn, but comparisons can be better shown on the single curve.

Now applying this principle to the case of the Captain's curve, Fig. 8, we will see that when a steady breeze is keeping her at, say, an angle of seven degrees, if the wind should slowly increase until she is heeled to fourteen degrees, the amount of dynamical stability expended in this increased inclination will be represented by the area *BFG*; for the whole dynamical stability will be represented by *ABFE*, of which the portion *ABGE* is due to the original force of the wind, leaving the remainder as the wind's increase.

If instead of the wind increasing slowly we suppose it to spring up with a sudden gust as when coming out from under the lee of a headland, the increase of work will be represented by the rectangle *BHFG*, and the ship will have to perform an equal amount of work

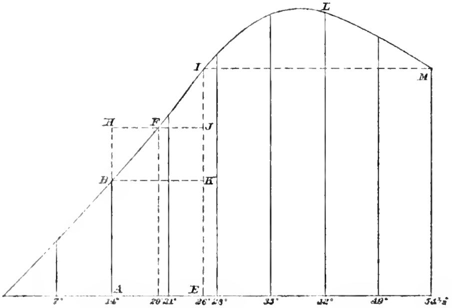
in order to resist this increase. She can do this only by inclining through an additional space, and returning back to some point below the 14 degree ordinate, oscillating either side until she gradually comes to rest with the steady heel of 14 degrees. It can readily be seen that in order to accomplish this, she will have to pass to such a point as will cut off a portion of the curve, whose area shall equal the area representing the excess of work which the wind has exerted; that is, *FIJ* must equal *BHF*.

Of course, it is hardly a supposable case to imagine that the wind will spring into being with the full force that it has when the ship has taken time to overcome her natural resistance and heeled back to it, so that strictly speaking the wind force should be represented by a curve, in direction between the curve of stability and the vertical side of the rectangle which we have taken to represent the sudden gust. Still if we take this extreme case, study the result and provide against that, we shall have done what any careful navigator would do—allow for contingencies; and we can easily charge the remainder, conceded to safety, to one of the many causes, such as shifting weights, heave of the sea, &c., which are likely to occur. We can here see why a reserve of dynamical stability is necessary.

It has been said that the edge of the Captain's deck was on a level with the water at 14 degrees, and Admiral Milne testified before the court-martial ordered on the loss of the vessel, that when he last went on the bridge with Captain Coles the vessel was sailing with the gunwale just awash, or she was heeled to 14 degrees. Now let us see what was likely to occur. But first we had better refer to the Monarch and by comparison show what will happen to the Captain.

Noticing Fig. 9, suppose a sudden gust of wind carries the Mon-

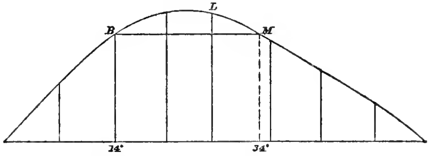
Fig. 9.



arch from 14 degrees to 20 degrees, and the momentum there takes her over until she reaches 26 degrees during the squall or until the sail is shortened. This "wind-work" (so to speak) represented by the rectangle *BHJK* has found its equivalent in the stability represented by *BIK*, the portion *BFJK* being common to both and *BHF* equal to *FJI*. The wind-work having then been overcome by the stability, measured by the ordinate *EI*, the ship is now forced back to 20 degrees, when the wind force represented by *AH* is just equalled by the stability.

Referring to Fig. 5, it will be seen that the Monarch and Captain have about the same stability up to 20 degrees, and as their weights or displacements are about the same (8036 tons and 7916 tons respectively) we may conceive that this force of wind will treat them each in the same manner. Hence we may consider that *BIK*, Fig. 9, representing the extra work done on the Monarch, also represents the extra work done on the Captain; and this will have to be deducted from the reserve of work or dynamical stability that she possesses before the squall springs up. This reserve is represented by *BLM* (Fig. 10) nearly, and this is less than *BIK*. The whole of

Fig. 10.



BLM will be absorbed, inclining the vessel to 34 degrees, and still leave a portion of the wind's demand unsatisfied. She will of course then go on inclining, her stability decreasing all the time, until she reaches 54½ degrees, where her stability is nothing and she will turn bottom upward.

This is more than likely what actually took place. The Captain while safe when heeled to more than 20 degrees under a steady pressure, when dynamically considered, was, while sailing at an angle of 14 degrees, carrying her people hovering on the brink of eternity.

It has been stated that the rectangle used in this discussion to represent the wind-work is not strictly accurate in its representation, for no squall can be so sudden as to strike the vessel with its maximum force, but will gradually increase from an initial velocity; conse-

quently the front side of the rectangle should be bent more or less into the form of a curve; nor is it possible for the force to have the same effect on the sails at all stages of the inclination, for as soon as the vessel begins to heel the wind strikes the sails at an angle, diminishing its effect by exposing less area as the inclination goes on.

Professor Rankin, I think it was, stated that this power varied as the $(\text{cosine})^2$ of the angle of heel.

It is better, however, to err as we have done, on the safe side, by representing the wind's instantaneous movement by a rectangle, rather than by the curve. But I will take the point up a little later.

Let us turn to our little ship, the Bache, which to me at least is somewhat nearer home.

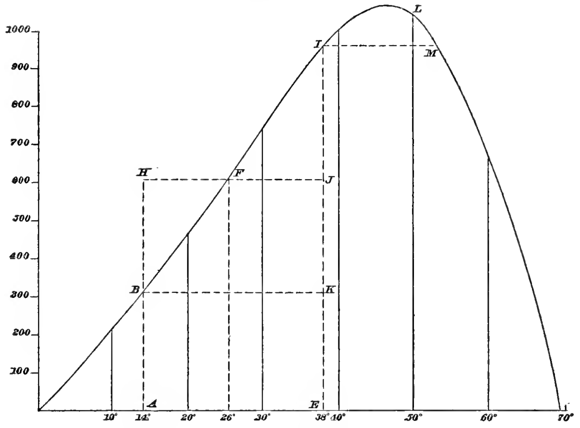
For her case I have supposed her to be struck suddenly by a squall with the force of six, or a fresh gale travelling with a speed of forty miles an hour, and a pressure of 7.9 pounds per square foot of canvas. We have all marked squalls larger than six in our log books, but remembering that ten in the tables quoted here represents a hurricane travelling at one hundred miles per hour (a rare occurrence at the sea level), we may consider this is an extreme case, as a careful officer will hardly be caught without some preparation in a heavier squall, and it is consequently assumed.

Applying this force at the centre of effort of all the Bache's sails, which gives a leverage from the middle draught of thirty-nine feet, and the moment is equal to 604 foot tons; quite a heavy stroke for a small vessel weighing only 383 tons herself.

Say she was already sailing under a force that inclined her to the same degree as the other vessels—14 degrees—turning to Fig. 11 where, in addition to the curve, I have represented on a vertical scale the force in foot tons, as worked out in the calculations for stability, we find that this force will augment the inclination to 26 degrees by its statical effect, and to 38 degrees by its dynamical effect. At which point the excess of wind-work, as shown by BHF, has been absorbed by the righting force shown by FIJ, leaving the latter still with a surplus represented by the area IML. So that our little ship is still safe, even under these trying dynamical conditions, which we have not made proportionate to her size, but have on the contrary taxed her with a greater burden than has been assigned to either the Captain or the Monarch.

We still have one more phase of the question to consider, and for which I have collected some data, but not enough to present for

Fig. 11.



discussion. I refer to the condition of the vessel as affected by waves.

It will be remembered that we have treated of smooth water circumstances only, and when we come to observe the existence of waves, we will find still greater cause for anxiety. We have accumulated evidence enough to show the instability of the Captain, and I feel confident I could show that our little vessel would throw off this additional burden, and come right side up under circumstances that would have probably capsized the Monarch. I do not like however to dispose of this case without showing an important point in the construction of these curves.

Professor Rankin, in the Report of the Committee on the Designs of English War Vessels referred to, writes as follows: "The curve of stability being given with ordinates proportional to the righting moment at different angles of heel, conceive to be drawn a curve with ordinates proportionate to the moments of pressure of the wind, of an altitude such that the segment cut off by it from the top of the curve of stability, shall cover an angle equal to the angle of vanishing stability required in order that the ship may be safe against the heave of the waves alone. This curve of moments of wind will divide the curve of stability into three areas; and the angle covered by the arc cut off at

the commencement of the curve of stability will be the limit which ought not to be exceeded by the greatest angle of heel produced by the wind alone, allowing for the dynamical effect of a sudden squall. The angle of steady heel ought not to exceed about one-half of the before-mentioned angle."

For this angle of vanishing stability Professor Rankin has assumed that of 39 degrees for both the Captain and the Monarch, and in connection with the curves he produced (Figs. 12 and 13), I have shown in Fig. 14 the curve of moments of wind for the Bache. As

Fig. 12.

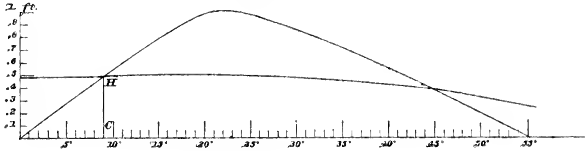


Fig. 13.

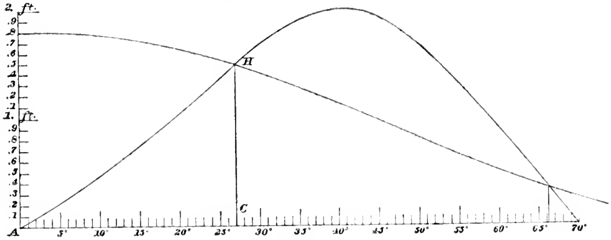
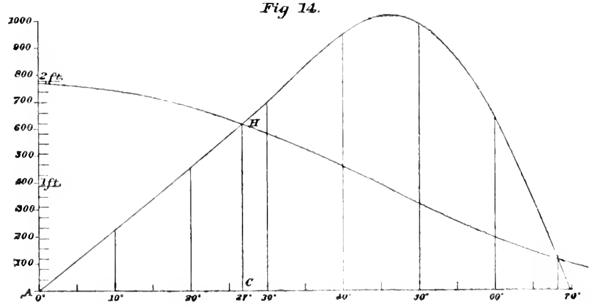


Fig 14.



has been noticed this is made by varying the ordinates indicating the wind's pressure as the (cosine)^2 of the angular inclination.

We must therefore consider in this case that the greatest safe heel by a squall when rolling in the trough of a long swell is 27 degrees, for both the Monarch and Bache, and the angle of steady heel ought not to exceed one-half of this, or 13½ degrees.

Referring the latter angle to the scale of foot tons in Fig. 14, we find it corresponds to a force of about 325 foot tons, or about 6 pounds pressure per square foot of all sail. Therefore when the Bache is carrying all sail in a seaway with a force of more than 5 she is in danger, but the Monarch is taking risks at a less pressure, and in the Captain it was time to reduce sail when there was a greater pressure than 1.6 pounds per square foot upon the canvas exposed to the wind.

You will please bear in mind that in this reasoning, which divides the curve of stability into two portions, the upper part devoted to resisting rolling produced by the waves alone, and the lower part, or from A to H, to the effect of wind on the sails, I have assumed the value for the vanishing angle of stability for the first cause as 39 degrees for the Bache; the same as was taken for both the Monarch and Captain. I might have made a nearer approximation to the true result from the data I have obtained, but it is hardly necessary, even if it were possible, to bring it within the limits of this paper.

The Bache being of less meta-centric height than either of the other vessels mentioned, we can safely place her vanishing angle, in pure wave motion, within the limits established by the commission, and the greater the difference, the more is left of her stability to overcome the pressure of the wind on the sails. Moreover, it is hardly possible that another commission, even if guided by the lamented Froude and Rankin themselves, would, in view of the extensive criticism which the report quoted has produced, have placed the minimum stability of any of these vessels at the low figures I have taken to represent the combined stability under all circumstances.

From what has gone before we deduce the fact that these three vessels, while having about the same measure of stability, as indicated by the old, or meta-centric method, will, as far as actual safety is concerned, come in the following order: Bache, Monarch, Captain. It is also apparent that this measure of safety is dependent upon the free board, the height of which is about 16 feet, 12 feet and 6½ feet respectively.

Fig. 15.

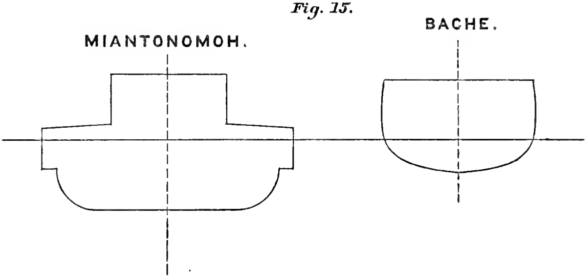
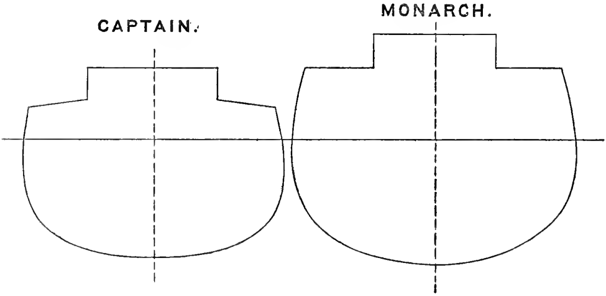


Fig. 16.

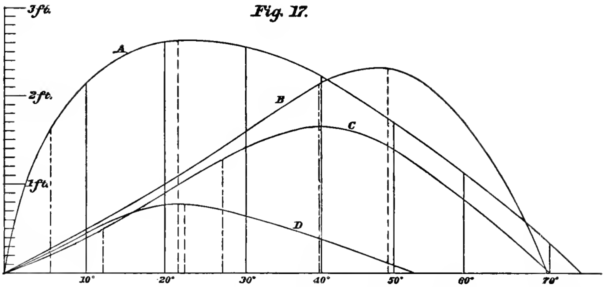


To show, however, that free board is not the all-important element as regards a vessel's safety, I will introduce one more curve, that for the monitor Miantonomoh.

This is simply an imaginary curve worked out for a vessel of similar general dimensions to those of the monitor, supposing that her centre of gravity was two feet below the load water line (others were made for distances of one and three feet), and was presented to the commission already referred to in this paper, for the purpose of making comparisons.

Here, then, is a vessel of very low free board—three feet—but a very great meta-centric height—15.8 feet,—and from Fig. 17 we see the value of the maximum righting moment is very great, but will also notice that the vanishing angle is only a little more than that for the Bache.

Fig. 17.



Were I discussing the rolling of vessels, I should also notice the marked steadiness of this vessel as compared with what it must be for a high-sided vessel of the same meta-centric height, but time does not permit.

I have not attempted to present in this paper the methods of arranging the tabulated statements for solving this problem, which represents in my case (owing to the irregular intervals at which it could be taken up) a great deal of time and labor. Notwithstanding, it contains really the gist of the whole subject, for I do not pretend to originality in its arrangement, but have simply applied the solution of a problem, long since deduced, to one of our own vessels. The space required for this example is too much to warrant my submitting it here, but those who may be interested in the subject can refer to the volume of the Transactions of the Institution of Naval Architects for 1871.

I cannot bring this paper to a close without expressing the hope that notwithstanding it has not been my fortune to present a paper on an original subject, it may have shown that officers, as laymen in this branch of science known as naval architecture, have it in their power to furnish the coming designers of our naval vessels with information which shall not only be useful to them in providing data on which they can base new theories (for to my mind this branch opens to the scientist an extensive field for cultivation), but which will surely be returned to us in information of the kind indicated in this discussion.

This will enable us to know more of the vessels we are required to handle than can be gotten from any other source, save, perhaps, experience acquired after a long cruise.

Take, for example, the rolling of ships, height, length and velocity of waves, in the different phases in which these subjects can be treated, and furnish the professional architect with all the data that we, in the ordinary routine of a man-of-war at sea, can obtain, and we shall surely reap benefits in better vessels, and more complete information in regard to the various points upon which information is desirable, before a commander takes his vessel to sea.

In conclusion, I desire to make my acknowledgments of the valuable aid I have received from Lieutenant H. F. Reich, U. S. N., who took the measurements, prepared the plans of the steamer Bache, and has verified a good portion of my work, without which aid I should have been forced to forego the pleasure of presenting to you the curve of stability for the Coast Survey Steamer Bache, treated under the general head of "Curves of Stability."

DISCUSSION.

THE CHAIRMAN.—Commander Chester's paper is now open for discussion. Its subject is one which should be very interesting to all of us. We are just preparing for what I hope is the beginning of a modern navy, and this question of stability will doubtless be carefully looked after in the design of our new ships. We have not made the mistakes of our English confrères in the construction of masted low freeboard ships, and we cannot but admire the energy with which they investigate, and seek to profit by disasters such as the loss of the Captain. Her loss it was which first thrust this subject forcibly upon the shipbuilding world, and the recent investigation of the loss of the Atalanta has advanced it a step further, at least in a practical way, so that it may now be said to be fairly in hand.

The principal difficulty in obtaining the curve of stability at present is to get the ship properly inclined in order to obtain the position of her centre of gravity. We have to rely a great deal upon commanding officers to make that careful preparation for the experiment which is necessary for accuracy and the general value of the test.

I have no doubt there are many points in Commander Chester's paper which will be more or less familiar to many of us, and I hope it will produce considerable discussion.

REAR-ADMIRAL C. R. P. RODGERS.—It will be a pity, Mr. Chairman, if the discussion of this paper be not thorough, for among the officers now present there is much knowledge of its subject-matter. In the old navy, with which the distinguished President of our Institute, now present, and

I were familiar in our early youth, shipbuilding was a handicraft rather than a science. Intelligent shipbuilders consulting with intelligent ship-captains managed to put upon the ocean vessels that commanded the admiration and the imitation of the world; but in later days the great change in the motive power of our ships, and in their armament and armor, has made new forms necessary; and the substitution of iron and steel for wood in shipbuilding has greatly complicated the question of stability and the distribution of weights. In those early days we heard little of the metacentric height, and we advanced empirically to the beautiful forms that our skilful shipbuilders gave our sailing vessels; in each new construction avoiding defects found in ships of earlier date. The old sloop-of-war Jamestown, with her light spar deck and high weights, would lie over upon her side in a moderate breeze, but so great was her reserve of stability that she has proved to be a safe, as well as fast, ship; others, with low weights, were very stiff, but gave unsteady gun platforms. We depended not much on scientific principles in those days, but upon an intelligent study of the performance of our ships at sea, and their builders were certainly very successful. Their successors are, or should be, naval architects, with the same natural aptitude, the same keen perceptions, with far better training, and with that precise knowledge of mathematics and physics which is indispensable in considering the complicated problems presented by the new methods of construction.

We are about to rebuild our navy, and Commander Chester has shown how much our sea officers may do to aid our constructors, by careful observations, numerous experiments, and well-considered reports, giving what their experience afloat has enabled them to observe at sea in all weathers and under varied circumstances. It was by such accord between the shipbuilder and ship-captain that our sailing ships of old were models for the world. Mathematics and skilled workmen will not suffice to give us good ships; the practical seaman must help the naval architect with his nautical experience, and we have now in our navy a large class of highly educated seamen, who, from the ships in which they serve, may send to our Bureau of Construction much well-digested and carefully stated information.

As an old officer I have been very glad to see these mathematical considerations in the construction of our ships so prominently brought forward to-night by Commander Chester, and I have heard his paper with much gratification. My only object in rising was to invite its discussion, after the remarks from the Chair.

Commander C. M. Chester.—I should like to say that the heeling of vessels is not so difficult a problem that we should not all take hold of it, and I think that if an officer will undertake it on going on board a vessel for the first time, he will see the usefulness of it in the advantage that he will gain by the knowledge of the ship he has to handle. It is a simple matter, possibly of a few hours' work while at a navy yard. The problem is given in all books on naval architecture, and need not be considered as a bugbear at all.

It is evident, I think, that we have it in our power to furnish naval architects with a great deal of data upon which they can base new theories. Quite

recently I have been addressed by a gentleman, whom I consider one of the leading scientists in Washington, if not in the country, who said if naval officers could give scientists information on the subject of waves, we would benefit very greatly all those who are engaged in scientific pursuits. I know from my own experience in endeavoring to study wave motion how defective is the knowledge we have on that subject at present. In this connection I prepared a small tabular form for circulation among our vessels in the Coast Survey, and requested the commanding officers to furnish me with all the data possible, so that I could, for my own satisfaction at least, have something on which to base my studies. It is a simple form, as follows: I rule off a page of foolscap paper, so as to have columns for the entry of the date, hour, course and speed, direction and force of the wind, and the oscillations of the vessel, or the angular inclination as shown by the pendulum, which, although not accurate, is still the best means we have, and will answer for the purpose until we obtain a better plan; then there are columns for the time of oscillation, the inclination of the pendulum, the windward and leeward roll, and the estimated length of the wave. This is done by taking the establishment of any two points on the vessel, opposite which the crests of two waves happened to be at the same instant of time, as she is going through the water. Two observers note the time of passage of the crest of the wave by these points, from which we can very easily get the length of the wave, or a very good approximation to it; of course, taking into consideration the course and speed of the vessel at the time, and the angle at which the wave is passing to or from the vessel. It is generally conceded that our knowledge of wave-motion is very defective; yet by devoting half an hour or less of each day to this subject, a great deal of information might be gained which would be of benefit to scientists as well as to ourselves.

REAR-ADMIRAL C. R. P. RODGERS.—Has not each ship its own period of oscillation, and is there any general principle which would affect all ships?

COMMANDER C. M. CHESTER.—Each vessel has its own periodic time. There is no general principle, except as to finding the length of the wave, but the object is to study the action of each vessel in the different character of waves. We estimate that the longest wave has a periodic time of twelve seconds, as reported by Scoresby, but that is simply a very crude statement, and we who go to sea can give more information on the subject than anybody else.

LIEUTENANT S. SCHROEDER.—On the subject of metacentric height, when the English Obelisk was carried from Alexandria to London, the vessel to take her was so designed as to have a metacentric height of only four inches; and so steady was she, that when being towed around from the place where she was launched, of a lot of Arabs who had perched on the top of the cylinder none were spilled off, although there was quite a sea at the time. She afterwards came to grief in the Bay of Biscay. There was a house built upon her, and when she got to heaving, her ballast shifted, and she was afterwards abandoned. For the same reason, when we were bringing the American Obelisk home, we put

the obelisk in the bottom of the Dessoug; then realizing what a weight we had at the bottom, we put 150 tons of stone a little below the water line; then the pedestal itself we put above the water line so as to raise the centre of gravity, and her motion was, I think, as easy as that of any vessel I have ever seen.

COMMANDER C. M. CHESTER.—If the Bureau of Construction will give us data, we can work more intelligently, instead of working without any information at all. The blank form supplied by the Bureau for the purpose of filling in the data for the behavior of vessels at sea is perfectly useless.

THE CHAIRMAN.—I think the form is now being revised.

LIEUTENANT A. ROSS.—If we give to each ship a journal in which to note all the points brought out on each cruise, then when the ship is fitted out later the constructors should enter in this journal the disposition of all her weights, state if any change was made in her and why it was done.

When the Portsmouth started upon her last cruise no data were supplied. We went to sea with the tanks stowed very high in order to clear the tank flooring. On reaching Portsmouth we found it advisable to put in an additional 50 tons of ballast. In taking out the tanks it was discovered that some of them had been chocked up from the bottom with timber to make them fit in. We simply substituted ballast for the chocks. After this change there was no better nor stiffer sailing ship than the Portsmouth. As I have said before, all these data should go in the ship's journal, and then each cruise would lead up to better sailing or better handling of the ship. As it is now, there are no such data supplied, which is much to be regretted.

COMMANDER C. M. CHESTER.—I hope we shall soon have Mr. Gatewood's paper on wave motion, when we shall undoubtedly receive much light on the rolling of ships. I think that the subject of metacentric height and disposition of weights in vessels is not generally understood by our people. I know in one case which happened not long since, there was some disposition to criticize our use of doubled-decked vessels, the idea being that the centres of gravity were taken so high as to be dangerous, and I should like very much to have it presented to us as practical officers in such a form as we shall all be able to grasp, a subject of so much importance to us who have to handle the vessels to be built.

THE CHAIRMAN.—In connection with the question of the safety of ships with low metacentric heights, it may be mentioned that the average merchant steamer, especially cargo steamers, have small metacentric heights but long ranges of stability. An interesting case occurs to me of a French Transatlantic liner, a great favorite with passengers on account of her easy motion, which was inclined at Havre shortly after the loss of the Captain and found to have a metacentric height of about twelve inches when ready for sea.

REAR-ADMIRAL C. R. P. RODGERS.—She doubtless was unsafe.

THE CHAIRMAN.—No, sir; I think with her high sides and small spread of sail she was probably perfectly safe. Low weights and high sides greatly extend the range of stability with a given metacentric height.

As regards the inclining of ships it is theoretically a very simple matter, yet practically the delicate nature of the experiment requires many precautions to be taken to ensure accuracy. There seems no sufficient reason why commanding officers should not, in many cases at least, incline their own ships. On most of our ships the guns are particularly available for the purpose.

The ship should be moored head to wind on a good day. The head lines should be made fast to some point near the water line, such as the bob-stay shackle; or if this be not possible, the lines should be gently slacked off at the time of the experiment. The bilges should be carefully freed from water; in flat-bottomed vessels a small quantity of water may seriously affect the results. The boilers should be preferably quite full; if steam is up in any of them, the rest may be filled only to steaming height, but this fact should be noted in the returns. All loose gear should be made fast in its proper place; running rigging hauled taut and made fast as nearly as possible; boats chocked; tiller secured; all pumping operations suspended; and the men stationed and kept in order.

Observations are best made with two pendulums, one of long period and the other of extremely short period. The pendulum of long length and period has a greater range along the straight edge base, and hence admits of less error in marking. The short period pendulum on the other hand moves so rapidly as compared with the ship that any slight oscillation which the ship will generally have is easily distinguished and separated from that of the pendulum. In all cases the mean inclination is marked. Should the long period pendulum have its bob swinging low down where it is dark, or should the experiment be performed at night, this fact may be made to aid us as follows: Let the long pendulum consist of a heavy plumb-bob hung by a fine wire, with a tolerably large ring at its end, over a nail driven horizontally into the centre of the head ledge of the hatch, but so that one corner of the nail shall be uppermost. In other words, the ring rests on an improvised knife edge. Pass two pieces of wood pressed tightly against the wire from top to bottom, to take out all torsion, and build out from the wire just above the straight edge in the hold a light wire bridge, with a socket at the end to hold a tallow dip. Moving away from the wire along the centre line of the ship, direct your companion to turn the bridge until the light and wire are in line. Then move the straight edge close up to the wire on the side opposite the light, and fix it horizontal by means of a spirit level, as nearly as any slight motion of the ship will allow. The observation may now be made with great accuracy by marking on the straight edge the extreme positions of the shadow of the wire corresponding to the inclined position of the ship, and taking a point midway to denote the mean inclination. I mention the above device because in many cases vessels can be very conveniently inclined at night, and the apparatus required is so simple as to be always at hand.

As a rule, the ship will be found to have a slight motion, and the motion of the pendulum should always be carefully observed, in order to separate as

far as possible the motion of the ship from any slight motion which may exist in the pendulum itself, the difference in period being generally sufficient for their distinction.

The short period pendulum may be suspended in any convenient place out of the wind, but preferably near the probable position of the ship's centre of gravity. In the latter case it may be used in connection with another simple experiment, which is at once so important and so easily carried out that it should never be omitted, viz. artificially rolling the ship. Every officer is familiar with the method of timing the men running across the deck so as to accumulate a roll, since some such method is adopted to loosen a ship when she has been run on a mud bank. Having accumulated a sufficient roll, say 10° to 12°, the men are stopped at the middle line, and the inclinations are marked by the short period pendulum at the centre of gravity, the corresponding times being noted by an officer stationed there with the ship's chronometer. We thus obtain the ship's still-water period, and an approximate measure of her rate of extinction of oscillation. The former of these shows her tendency to take up oscillations in a given state of the sea, and the latter is a measure of the resistance which she offers to accumulation of large angles of roll. All French ships in commission are rolled for the purpose of obtaining their still-water period. I can see no reason why our vessels should not in all cases be inclined and rolled before sailing on a commission, and at other times when the opportunity offers.

NAVAL INSTITUTE, ANNAPOLIS, MD.

MAY, 1883.

NOTES ON THE LITERATURE OF EXPLOSIVES.*

PROF. CHAS. E. MUNROE, U. S. N. A.

No. IV.

By far the most complete and valuable original contribution to the study of explosives which has been made in this country is the work of General Henry L. Abbot, Eng. Corps, U. S. A., which has been published by the War Department, under the title "Report upon Experiments and Investigations to develope a System of Submarine Mines for defending the Harbors of the United States," being No. 23 of the Professional Papers of the Corps of Eng., U. S. A. In a quarto of 444 pages, fully supplied with illustrations, diagrams and tabulated data, General Abbot gives the results of thirteen years of experimental investigation and mathematical study of the data thus obtained.

The chief end of all the experiments was the determination of the distance at which a given charge of a given explosive would crush a ship of war as now constructed. Starting with an empirical formula, with its undetermined constants and its variables, embracing the various conditions involved in the explosion under water of mixtures and compounds converted almost instantaneously into gas, General Abbot has, by comparison and analysis of the measured results of a large number of experimental trials, brought it to a definite and determined form, giving a final expression for the absolute shock of the explosion as conveyed through water at different distances, at different depths, and in different directions. Incidentally other questions of interest have arisen for solution and have met with experimental inquiry.

* As it is proposed to continue these notes from time to time, authors, publishers, and manufacturers will do the writer a favor by sending him copies of their papers, publications, trade circulars, or expert testimony in infringement cases.

The first step in the investigation was naturally the experimental determination of the force of a unit weight of each explosive, and it became necessary to examine the relative value of the dynamometers available for the measurement of this force. The two forms which meet with general acceptance are Rodman's pressure gauge and Nobel's crusher gauge. Accepting the latter as more suitable for these experiments, it was decided to use lead cylinders, formed by casting and compression, to register the crushing force, rather than copper, since the latter metal is too hard for use in registering very small pressures even when a large diameter of piston is used. The requisite degree of sensitiveness was secured by employing five different sizes of lead cylinders to register the work of the explosion as transmitted by the piston, and to further extend the scale three different sizes of piston were adopted. To measure the compression of the cylinders, use was made of a standard scale having one fixed and one sliding contact piece, and reading by a vernier correctly to one-thousandth of an inch. The rapidity and accuracy of this method leave nothing to be desired.

The mathematical problem of so interpreting the lead compressions effected by a subaqueous explosion as to derive from them a correct idea of the destructive effect likely to be exerted upon a ship, required careful consideration.

At the instant of explosion, a certain quantity of gas, depending upon the nature and weight of the charge, is developed with a degree of suddenness varying with its chemical composition and the mode of ignition. The free expansion of this gas being resisted by the inertia developed in the water, a certain amount of mechanical work is instantaneously performed, resulting in the formation of a chamber filled with the highly heated products of the chemical reaction. The pressure of the surrounding water, joined to the original impulse, gives a rapid motion to this chamber along the line of least resistance, which in general coincides with the vertical drawn through the centre of the charge. A rush of gas and water into the air is the result; which, in the case of a large charge exploded near the surface, often presents an imposing spectacle. This phenomenon is analogous to what occurs at the discharge of a cannon. The line of least resistance corresponds to the axis of the bore, while the water around plays the part of the metal of the gun.

A vessel in the vicinity may be exposed to three distinct dangers: 1st. Its hull, embedded in the aqueous cannon, may be ruptured by

the initial shock transmitted from molecule to molecule through the fluid. 2d. Should the hull be situated near the vertical through the charge, its resistance may prove to be less than that of the superincumbent water; and the line of least resistance may thus be deflected from its normal direction and traverse the vessel. 3d. In the case of the enormous charges sometimes employed in submarine mining, the waves generated by the explosion may rack the vessel beyond its power of endurance, or by rising amidships may even break her in sunder.

Unless an actual vessel be available for the experiment it is evident that the pressure-gauge can only be arranged to measure the first of these three causes of destruction. The instrument virtually forms part of the aqueous cannon and chiefly registers the kinetic energy transmitted from molecule to molecule of the fluid. Fortunately this is the primary cause of rupture, and conclusions based upon the gauge indications may therefore be accepted at the best attainable of the destructive force of the explosion.

To rupture the bottom of a vessel is to perform mechanical work; that is, there must be an effective motion of the point of application of the force along the line of its direction. This motion being much greater than in the bursting of a cannon, *time* becomes a more important element. Hence in comparing different explosives under varying conditions as to distance, submergence, mode of ignition, etc., regard must be had to the amount of mechanical work to be performed, rather than to the intensity of the forces developed; but it must not be forgotten that a certain amount of the latter is needful to overcome the resistance of the hull suddenly, before the available energy can be dissipated upon the water or upon a general lateral movement of the ship. In fact, it is possible to conceive that with the same potential energy an explosion may be so sudden and short-lived as to fail to supply the continuous force necessary to effect the destruction of the hull; or, on the other hand, that its force may be developed so slowly as to be expended in general harmless motion. It would appear, therefore, that the *mean intensity* of the force acting upon the ship during the time of explosion is the quantity most important to be determined.

In 1865 Prof. W. H. C. Bartlett, in a paper read before the National Academy of Sciences, criticized the method of Rodman of attempting to evaluate the cut produced on the copper in the gauge of a gun by a comparison with the cut produced by pressure in his machine, and

he pointed out the difference in effect which must necessarily exist between the dynamic action of the gases and the static pressures of the machine. To avoid this error Gen. Abbot constructed a pendulum of considerable weight, and fixed his crusher gauge rigidly at such a point that it would receive the full force of the blow from the hammer falling through a measured arc. The value of the compression of the cylinder was thus determined in foot pounds. To connect this with the mean pressures recorded by the Rodman machine he exposed copper disks to the action of the Rodman indenting tool under the same circumstances. Other improvements were the invention of a device to exclude water from the gauge and a clutch to prevent the hammering of the piston.

Two forms of apparatus were employed for holding the gauges during the experimental explosions. First, the Ring apparatus, devised by Major King in 1865, of which four sizes, 3, 4, 5 and 8 feet respectively in interior diameter, were employed. They were made of the best wrought iron 1.5 inches thick and 4.5 inches wide in the plane of the ring. Each ring held six gauges equidistant from each other, and the ring was suspended vertically. The buoy supporting the ring had also a gauge inserted in its bottom. Second, the Crate apparatus, used for measuring the energy developed by an explosion in the immediate vicinity of the torpedo, and at certain points vertically over it. It consisted of a rectangular wrought iron frame 50 feet long, 10 feet wide and 10 feet deep, and it carried 36 gauges. The two buoys supporting it were also each supplied with a gauge. In the course of the experiments it became evident that the gauges must be held rigidly in position, and this condition was fulfilled in the Crate apparatus. In both apparatuses the charge was held in the centre. Charges of from 5 to 50 pounds of dynamite were used with the crate, and it was finally destroyed by a charge of 100 pounds. Experiments were also conducted against wooden and iron targets representing a section of a modern ship of war.

The height and form of a jet of water thrown into the air by a given charge is observed to vary enormously with its submergence, and is probably a delicate index of the combined effect of all the forces transmitted to the surface of the water. It might seem that this feature could be turned to account in studying certain important matters, such, for example, as the effect of varying the strength of case for gunpowder charges, and Capt. Vandevelde, of Holland, based his system of subaqueous measurements upon it. The subject was care-

fully investigated both instrumentally and by the aid of instantaneous photography, and it was found that the disturbing action of even very slight currents of air; the varying effects dependent upon the relative position of the sun, the jet, and the observer; the excessive tenuity of the ill-defined cloud of mist which shrouds the main body of water; and, lastly, the rapidity with which the different phases succeed each other, combine to throw too much uncertainty upon the phenomenon to render it a safe basis for important practical conclusions.

In using the Ring apparatus with explosive *mixtures* it was observed that in each individual shot there was a decided maximum intensity in *some* direction, owing probably to the case holding the charge giving way at that point, but the study of the final results proved that, with explosive *mixtures*, there is no well-marked difference in the initial intensities of action in different directions in a vertical plane passing through the centre of explosion, when the number of observations is sufficiently multiplied to eliminate the disturbing effect of anomalies.

In the study of the characteristics of the subaqueous explosions it was determined to examine fully only one typical explosive of each class, trusting that a few shots, carefully planned, would develop the peculiarities of others of the same general nature. Mortar powder was selected as a fair type for chemical mixtures, and dynamite No. 1 for chemical compounds. For comparison with mortar powder other varieties of gunpowder, together with Oliver powder (in which part of the carbon was replaced by uncarbonized peat) and the Oriental Safety compound (consisting of gambier and potassium chlorate), were taken. In order to compare the strength of dynamite No. 1 in subaqueous explosions with that of other explosive compounds, shots were fired with gun-cotton, dualine, nitro-glycerin, dynamite No. 2, mica powder, vulcan powder, rendrock, hercules powder, electric powder, Designolle powder, Brugere or picric powder, and explosive gelatine.

In comparing the results obtained for pure nitro-glycerin with those for dynamite No. 1 there was revealed what at first sight appears to be a paradox. One pound of pure nitro-glycerin was found to exert only 81 per cent. of the intensity of action of three-fourths of a pound absorbed by an inert substance which could add nothing to the heat or gases developed. This fact, which was discovered early in the trials, was considered so extraordinary as to require careful

verification and study. The first explanation suggested was that it was due to a possible variation in the strength of the nitro-glycerin itself depending upon a difference in the chemical composition of different samples. This was tested practically with different nitro-glycerins and with nitro-glycerin and dynamite made from it, and it was shown, beyond question, that variations in the quality of the nitro-glycerin had nothing to do with it, and that the explanation must be sought in the physical conditions of the problems. General Abbot, therefore, suggests that in granulating nitro-glycerin, by absorbing it in kieselguhr, the particles of silica slightly retard chemical action,—since in detonation the reactions occur within the molecules,—and as the resistance opposed by water is of a slightly yielding character, more time may be required to reach this condition than is afforded by nitro-glycerin pure and simple. This view is confirmed by the action of certain dynamites which are so prepared as to explode with exceeding rapidity and which fall very low in the scale. They are evidently so quick as to be unsuited for subaqueous work.

As the result of this branch of his investigation, General Abbot concludes that as regards permanency, power, convenience and readiness in manufacture, dynamite No. 1 is the best explosive for our submarine mines. Hence in studying the destructive effect of subaqueous explosions this compound was exclusively used. In the discussion of the results obtained comparisons were made with those obtained in England, France, Sweden and elsewhere.

As a result of this investigation it is found that if we adopt an instantaneous pressure of 6500 lbs. per square inch as the measure of a fatal shock to a first-class ship-of-war, the following are the extreme destructive ranges of submarine mines :

	Charge, pounds.	Horizontal range, feet.	Vertical range, feet.
Dynamite No. 1	100	16.3	18.6
Gun-cotton	100	14.7	17.3
Explosive gelatine	100	18.2	20.3
Sporting powder, 1 fuse per cubic foot	100	3.3	3.3
" " 1 central fuse	100	3.1	3.1
Dynamite No. 1	200	22.6	25.9
Gun-cotton	200	20.5	24.1
Explosive gelatine	200	25.3	28.2
Sporting powder, 1 fuse per cubic foot	200	7.4	7.4
" " 1 central fuse	200	6.6	6.6

Dynamite No. 1	500	35.0	40.0
Gun-cotton	500	31.7	37.3
Explosive gelatine	500	39.1	43.7
Sporting powder, 1 fuse per cubic foot .	500	19.5	19.5
" " 1 central fuse . . .	500	16.2	16.2

The smallness of the additional range obtained by increasing the charge from 200 to 500 lbs. has led to the adoption of the 200-lb. charge for shallow harbors.

The general formula for the extreme destructive range ($⅃$) of a submarine mine charged with an explosive compound and acting upon a first-class ship-of-war, which has resulted from this investigation and from which the foregoing table has been computed, may be placed under the following form, for convenience of application:

$$⅃ = \frac{\sqrt[2.1]{(\vartheta + E)C}}{8} \text{ in which}$$

$⅃ =$ range in feet,

$C =$ the weight of the explosive in pounds,

$E =$ a constant to be determined by experiment. (It is for dynamite 186 and for gun-cotton 135.)

$\vartheta =$ the angle with the vertical passing through the centre of the charge, made by a line drawn from that point to the surface exposed to the shock, reckoned from the nadir and expressed in degrees.

If the vessel lies at this or a less distance she will be destroyed; if at a greater distance she will escape rupture of the hull. A submergence of the charge properly suited to its size is supposed—say not less than three or four feet for one hundred pounds and proportionally greater for larger amounts. By this mode of treatment the results are made general. Suppose, for example, that the strength of the hulls of ships-of-war should be increased. A corresponding change in the constant 8 would indicate the new requirements. Suppose that some new explosive compound should prove to be better suited to the work than dynamite. A new value for the constant E is all the change that would be required. It will therefore be comparatively easy hereafter to keep pace with modern progress.

The remainder of the report is devoted to the investigations of electrical fuses and of the various forms of igniting apparatus, and it is distinguished by the same fullness, accuracy and thoroughness which characterize the portions abstracted. The appendices contain

full details of upwards of 700 explosions, which may be used in any further discussion of this subject.

A new form of dynamite is proposed, in which ninety parts of dynamite or blasting gelatine are mixed with ten per cent. of india rubber in sufficient solvent to dissolve it. The whole is thoroughly stirred and the solvent evaporated; the mixture is then packed in rubber cartridges.—*Jour. Soc. Chem. Ind.* and *School of Mines Quarterly*, **4**, 3, 239, April, 1883.

The School of Mines Quarterly **4**, 1, 15th September, 1882, contains a paper by Arthur H. Elliott, F. C. S., "On Nitro-glycerin," which records the solvent action of a large number of substances on nitro-glycerin. In making these experiments it was found impossible to heat nitro-glycerin near the boiling point of water without some of it evaporating. Ammonic sulphydrate and ferrous chloride both reduced nitro-glycerin when hot. The action of ammonic sulphydrate is shown thus:

Two quantities, 3.847 and 3.758 grams of nitro-glycerin were each dissolved in twenty-five cubic centimetres of absolute alcohol, and each was treated with about fifty cubic centimetres of ammonic sulphhydrate solution (made by saturating ammonic hydrate, sp. gr. .98, with sulphuretted hydrogen). The solutions became hot, dark colored, and sulphur separated which dissolved again when more ammonic sulphydrate was added, much ammonia being given off during the action. The solutions were now evaporated to dryness to expel the excess of ammonia and ammonic sulphydrate. The residue containing separated sulphur was treated with water, the solution filtered and the residue washed with water. The filtered solution and washings were now evaporated until the weight was constant. The glycerin so obtained weighed 1.552 and 1.540 grams, which is equal to 40.34 and 40.97 per cent. on the nitro-glycerin taken, while the theoretical figures are 40.52 per cent. Ammonic sulphydrate, therefore, reduces nitro-glycerin and gives practically the theoretical quantity of glycerin.

In the paper of Prof. H. Debus on the "Chemical Theory of Gunpowder" (*Nav. Inst. Proc.* **9**, 1, Mar. 1883), on page 74, he repeats the error concerning the composition of the United States regulation powder which is found in many foreign books. The United States regulation gunpowder is composed of 75 parts of saltpetre, 15 parts of charcoal and 10 parts of sulphur.

From *Census Bulletin*, No. 304, we learn that there were in 1880 in the United States, 39 factories for the manufacture of explosives and fireworks, having a capital of $579,750, and employing 313 men, 217 women and 205 youths. The wages paid during the year amounted to $216,069; the value of the materials was $840,877, and of the products, $1,391,132. 33 establishments with a capital of $4,983,560 were devoted to gunpowder; 988 men, 20 women and 3 youths were employed. The wages amounted to $510,550, the value of the materials to $2,053,488, and of the products to $3,348,941. There were 21 factories for the high explosives, with a capital of $1,605,625. 328 men and 1 woman were employed, and their wages were $164,864. The value of the material was $1,218,061, and of the product, $2,453,088.

Under the title "Dust Explosions in Breweries," C. John Hexamer gives in *Jour. Frank. Inst.* [3] **85**, 2, 121, February, 1883, an account of the causes of these explosions and the precautions to be taken and devices invented for preventing them. He especially dwells upon the necessity of removing bits of iron from the grain by passing it over a plate magnet; the lining of the elevator with copper, and the use of geared rollers with spring clamps in place of friction rollers.

In the same journal, page 135, in a "Summary of Progress in Science and Industry for 1882," reference is made to the use of caustic lime as a substitute for gunpowder in coal mines. The lime is made into cartridges by a hydraulic pressure of 40 tons. By a simple and inexpensive method these cartridges are confined in the bore holes in such a manner that when a quantity of water is forced into contact with them, the combined effect of the steam generated and the expansion of the lime in slacking breaks the coal out in from 10 to 15 minutes and without wastage from pulverization. The process has been in use now for some time and works well.

Mem. Soc. Eng. Civ. September, 1882, page 270, gives an interesting and detailed account of the removal of an iron wreck in the channel of the Danube which was dangerous to shipping. 790 kilos of explosive gelatine and 475 kilos of dynamite No. 1 were used, the former costing $1 per kilo and the latter 64 to 80 cents per kilo in Vienna. The total cost of removal was $7250, and the work occupied two months.

Dr. C. William Siemens, in his presidential address before the British Association for the Advancement of Science entitled "Science in Relation to the Arts," says that when the Association met at Southampton on a former occasion, Schonbein announced to the world his discovery of gun-cotton. This discovery has led the way to many valuable researches on explosives generally, in which Mr. Abel has taken a leading part. Recent investigations by him in connection with Captain Noble, upon the explosive action of gun-cotton and gunpowder confined in a strong chamber (which have not yet been published), deserve particular attention. They show that while by the method of investigation pursued about twenty years ago by Karolyi (of exploding gunpowder in very small charges in shells confined within a large shell partially exhausted of air) the composition of the gaseous products was found to be complicated and liable to variation, the chemical metamorphosis which gun-cotton sustains, when exploded under conditions such as obtained in its practical application, is simple and very uniform. Among other interesting points noticed in this direction was the fact that, as in the case of gunpowder, the proportion of carbonic acid increases while that of carbonic oxide diminishes with the density of the charge. The explosion of gun-cotton, whether in the form of wool, or in the form of loosely spun thread, or in the packed compressed form devised by Abel, furnished practically the same results if fired under pressure, that is, under strong confinement—the conditions being favorable to the full development of its explosive force; but some marked differences in the composition of the products of metamorphoses were observed where gun-cotton was fired by detonation. With regard to the tension exerted by the products of explosion, some interesting points were observed, which introduce very considerable difficulties into the investigation of the action of fired gun-cotton. Thus, whereas no marked differences are observed in the tension developed by small charges and by very much larger charges of gunpowder having the same density (*i. e.* occupying the same volume relatively to the entire space in which they are exploded), the reverse is the case with respect to gun-cotton. Under similar conditions in regard to density of charge, 100 grams of gun-cotton gave a measured tension of about 20 tons on the square inch, 1500 grams gave a tension of about 29 tons (in several very concordant observations), while a charge of 2.5 kilos gave a pressure of about 45 tons, this being the maximum measured tension obtained with a charge of gunpowder of five times the density of the above.

The extreme violence of the explosion of gun-cotton as compared with gunpowder when fired in a closed space was a feature attended with formidable difficulties. In whatever way the charge was arranged in the firing cylinder, if it had free access to the enclosed crusher gauge, the pressures recorded by the latter were always much greater than when means were taken to prevent the wave of matter suddenly set in motion from acting directly upon the gauge. The abnormal wave pressures recorded at the same time that the general tension in the cylinder was measured, amounted in the experiment to 42.3 tons, where the general tension was recorded at 20 tons; and in another where the pressure was measured at 29 tons, the wave pressure recorded was 44 tons. Measurements of the temperature of explosion of gun-cotton showed it to be about double that of the explosion of gunpowder. One of the effects observed to be produced by this sudden enormous development of heat was the covering of the inner surfaces of the steel explosion-vessel with a network of cracks, small portions of the surface being sometimes actually fractured. The explosion of charges of gun-cotton up to 2.5 kilos in perfectly closed chambers, with development of pressures approaching to 50 tons on the square inch, constitutes alone a perfectly novel feat in investigations of this class. Messrs. Noble and Abel are also continuing their researches upon fired gunpowder, being at present occupied with an inquiry into the influence exerted upon the chemical metamorphosis and ballistic effects of fired gunpowder by variation in its composition, their attention being directed especially to the discovery of the cause of the more or less considerable erosion of the interior surface of guns produced by the exploding charge—an effect which, notwithstanding the application of devices in the building up of the charge specially directed to the preservation of the gun's bore, has become so serious that, with the enormous charges now used in our heavy guns, the erosive action on the surface of the bore produced by a single round is distinctly perceptible. As there appeared to be *prima facie* reasons why the erosive action of powder upon the surface of the bore at the high temperatures developed should be at any rate in part due to its one component sulphur, Noble and Abel have made experiments with powders of usual composition and with others in which the proportion of sulphur was considerably increased, the extent of erosive action of the products escaping from the explosion-vessel under high tension being carefully determined. With small charges a particular powder containing no sulphur was found to exert

very little erosive action as compared with ordinary cannon powder; but another powder containing the maximum proportion of sulphur tried (15 per cent.) was found equal to it under these conditions and exerted very decidedly less erosive action than it, when larger charges were reached. Other important contributions to our knowledge of the action of fired gunpowder in guns, as well as decided improvements in the gunpowder manufactured for the very heavy ordnance of the present day, may be expected to result from a continuance of these investigations. Professor Carl Himly, of Kiel, having been engaged upon investigations of a similar nature, has lately proposed a gunpowder in which hydrocarbons precipitated from solutions in naphtha take the place of the charcoal and sulphur of ordinary powder. This powder has amongst others the peculiar property of completely resisting the action of water, so that the old caution "keep your powder dry," may hereafter be unnecessary.—(*Jour. Frank. Inst.* **115**, 687, 215, March, 1883.)

All of the explosive substances in common use are believed to owe their explosive properties to the fact that they contain nitrogen which exists wholly or in part in the body, united with oxygen, in the form of nitryl NO_2. There is yet another class of nitrogenized bodies, some of which are explosive, which may be regarded as formed by the replacement of two atoms of hydrogen (in two molecules of an aromatic hydrocarbon) by two atoms of nitrogen. A body so constituted is called an *azo* compound. Diazobenzene $C_6H_5 - N \equiv N - C_6H_5$, which may be formed by the indirect substitution of hydrogen by nitrogen in benzene, is a type of this class. It stands intermediate in composition between nitro-benzene and aniline. Diazobenzene is a quite unstable substance, while the nitrate is a crystalline solid, which is employed in the arts for the manufacture of dye-stuffs, and which is so explosive that it has been proposed for use as a detonating primer. It may be formed by the action of nitrous acid on phenylammonium nitrate according to the reaction

$$(H_3, C_6H_5 \equiv N) - NO_3 + HNO_2 = C_6H_5 - N_2 - NO_3 + 2H_2O.$$

Berthelot and Vieille have recently made a study of the properties of diazobenzene nitrate, *Annales de Chimie et de Physique* [5] **27**, 194, Oct. 1882, and they consider it as representing the residue of two nitrogenized bodies which have lost, the one (nitrous acid) its oxygen, the other (aniline) a part of its hydrogen, in the act of com-

bination; but a notable portion of the energy of these elements remains in the residue, which accounts for its explosive character. They have examined this substance in the same way as they have done for fulminating mercury.* If preserved in dry air out of contact with the light it can be kept for two months and more, but exposed to daylight it slowly changes; in moist air the change is rapid, and in contact with water it is decomposed immediately. It is as sensitive to a blow as mercuric fulminate. On heating it detonates with extreme violence at about 90°, while mercuric fulminate detonates at about 195°. Slowly heated at a lower temperature it slowly decomposes. Its density is 1.37. Total heat of combustion under constant volume + 783.9 cal. and under constant pressure + 782.9 cal. Heat of formation — 89 cal. showing it to be an endothermic † substance like the other high explosives. The heat of combustion was determined by burning in oxygen; so the heat formed during detonation, pure and simple, was also measured and was found to be + 114.8 cal. per equivalent or 687.7 cal. per kilo. The volume of the gases produced was 817.8 litres per kilo or 136.6 litres per equivalent consisting of

HCN	3.2	and for 136.6 litres 4.4
CO	48.65	66.4
CH_4	2.15	2.9
H	27.7	37.9
N	18.3	25.0
	100.00	136.6

We notice in the reaction that a considerable quantity of hydrocyanic acid results; that the oxygen all unites to form carbon protoxide, no water being formed; three-fourths of the nitrogen is liberated in the free state, and a fifteenth in the state of hydrocyanic acid. The remainder of the nitrogen is found in the carbonaceous residue, about one-fifth existing as ammonia and the remainder in a peculiar state of combination with the carbon. Of the five equivalents of hydrogen about three and one-half exist free; a half equivalent forms marsh gas, a half ammonia and hydrocyanic acid, and about a half is united with the carbon. One-half the carbon forms carbon protoxide, and a ninth of the remainder exists as marsh gas and hydrocyanic acid. The solid residue contains four-ninths of the carbon. The empirical formula of the residue is $C_5H_2N_2$. It is then a carbon rich in hydro-

* Proc. Nav. Inst., Vol. VIII, p. 441. † Proc. Nav. Inst., Vol. VIII, p. 305.

gen and nitrogen probably combined under the form of condensed and polymeric bodies. By calculation the gaseous products contain 75.9 per cent. of the weight of the substance; there remains 24.1 per cent. of residue in the form of a very voluminous black, impalpable powder with an ammoniacal odor. The ammonia in the residue was 00.11 per cent., and in the gas 00.0042 per cent. The following table represents these results in 1000 parts by weight:

Nitrogen	free	189.7		
	as HCN	16.7	215.6	
	as H_3N	9.2		251.2
	combined with the carbon		35.6	
Oxygen as CO				287.6
Hydrogen	free	20.5		
	as CH_4	3.2	26.9	
	as HCN	1.2		
	as H_3N	2.0		29.9
	combined with the carbon		3.0	
Carbon	as CO	215.8		
	as HCN	14.3	239.6	
	as CH_2	9.5		431.3
	carbon		191.7	

Summary.

Gaseous products	769.7	1000.0
Residue	230.3	

Neglecting the secondary products the reaction may be written

$$C_6H_5 - N_2 - NO_3 = 3CO + 3C + 5H + 3N$$

but ammonia, marsh gas and hydrocyanic acid are formed as secondary products.

The simple decomposition in accordance with the above reaction should liberate + 204.7 cal. under constant volume instead of + 114.8 as found. This shows that the secondary products have absorbed — 89.9 cal. during their formation. This absorption results chiefly from the formation of the compound of carbon and nitrogen. The exothermic formation of the ammonia and marsh gas very nearly compensates for the endothermic formation of the hydrocyanic acid. This agrees with the general observation that the hydrocarbons, rich in carbon and carbonaceous matter, retain a notable portion of the energy of the complex bodies from which they are derived. It surpasses in some instances the energy of the elements themselves. This observation, first made by Berthelot on acetylene, is quite

generally applicable to pyrogenous decompositions, and serves to explain the singular conditions under which certain endothermic compounds are formed even at the moment when the heat destroys the organic compound.

It remained to determine the tension in a closed vessel. This was determined by the method used for mercuric fulminate, with the following result:

Density of charge.	Weight of charge, grams.	Pressure in kilos per cm.^{2}	Pressure with mercuric fulminate.
0.1	2.37	990	480
0.2	4.74	2317	1730
0.3	7.11	4581	2700

The pressures for diazobenzene nitrate are greater than those for mercury fulminate for the same density of charge, but on the contrary mercuric fulminate will develop a much greater pressure (24,000 kilos instead of 7500 kilos) when detonated in its own volume, on account of its greater density. The destructive effects of the two explosives differ, following the density of charge. On contact the effect is much more marked with mercuric fulminate.

The same number of this journal, p. 202, contains an article by Berthelot and Vieille, entitled "Researches on Nitrogen Sulphide." The nitrogen sulphide is formed by the action of sulphur chloride on ammonia, and is obtained in well-defined crystals having the formula of NS corresponding to nitric oxide. The substance is not affected by dry or moist air, and has been several times heated to 50° without change. It detonates under the hammer, but is less sensitive than diazobenzene nitrate or mercuric fulminate. It deflagrates at 207°, but more slowly than mercuric fulminate. The pressures developed by the explosion of nitrogen sulphide are very nearly the same as those obtained for mercuric fulminate with a density of 0.2 and 0.3 of charge. But these relations are somewhat uncertain, and cause the very marked difference which exists in the rapidity of decomposition of the two bodies. On account of this the effects produced by the two bodies used as detonators and in fuses ought to be very different.

NAVAL INSTITUTE, ANNAPOLIS, MD.

MAY, 1883.

SURFACE CONDENSERS.

BY CADET ENGINEER J. M. WHITHAM, U. S. N.

The old practice of making the condensing surface a certain percentage of the heating surface of the boilers has been largely followed by designers, and is even now recommended by many engineers. But it is evident there can be no relation between them ; for the condensing surface depends upon its efficiency, the initial temperature of the exhaust steam, and the temperature of the feed, injection and discharge waters ; whereas the heating surface depends upon its efficiency, type of boiler, quality of coal used, and furnace draught.

It would thus appear that if the temperatures in the condenser were nearly alike for all marine engines, there should be some definite ratio between the amount of surface for condensation and the designed I. H. P. This, however, is not a safe rule, because the pounds of steam per I. H. P. per hour vary, being different with simple, two-cylinder compound and triple-expansion engines, and if they are steam- or air-jacketed, and no doubt has its minimum value where properly designed steam-jacketed, triple-expansion engines are used.

In the *Marine Steam Engine*, by Chief Engineer Richard Sennett, R. N., the condensing surface is stated as being from 2.00 to 2.50 square feet for each designed I. H. P., while *A Manual of Marine Engineering*, by Prof. A. E. Seaton, has the following table, where the temperature of the sea is 60° F., viz:

Absolute Pressure of Exhaust Steam.	Square Feet of Condensing Surface per I. H. P.
30 pounds,	3.00
20 "	2.50
15 "	2.25
12.5 "	2.00
10 "	1.80
8 "	1.60
6 "	1.50

and he says that when the vessel is intended to cruise in the tropics the value must be increased 20 per cent., and when she occasionally visits the tropics, increased 10 per cent., while 10 per cent. less will give good results in Arctic waters. Table I, appended, shows the ratio referred to as applied to English and American marine engines. Comparing like types of the two services, there is considerable difference in the values of the ratio, which cannot be due entirely to the use of independent pumps. The Leila should not be classed with any of the other vessels, as she has a Herreshoff condenser with excellent circulation: but it verifies M. Peclet's experiments, *which proved that the thermal conductivity of a metal is increased when the circulation is improved.* The table shows that smaller condensers may be used with independent pumps than otherwise.

A number of experiments were conducted at the Ouseburn Engine Works of Newcastle-on-Tyne by Mr. B. G. Nichol (see *Engineering*, Vol. XX, p. 449), but clean brass tubes only were used, and laboratory results were attained rather than those belonging to surface condensers in ordinary use. He found the thermal conductivity of brass to be about equal to the value determined by Chief Engineer Isherwood, U. S. N., but his laws differed somewhat, and, as Mr. Isherwood has determined the conductivity of several metals by a long series of carefully conducted experiments, his laws will be used in deducing a formula for the amount of condensing surface.

Mr. Isherwood found (see p. 57 of Shock's *Steam Boilers*) that the weight of water vaporized in a given time is in *direct ratio of the difference of temperature of the sides of the intervening metal, and independent of its thickness.* He found that the thermal conductivity of brass in terms of heat units transmitted per hour through one square foot is 556.832 for a range of 1° F. These experiments apply equally well to a surface condenser under like conditions, since heat is always transmitted from the warmer to the colder side.

By means of these results the following formula may be deduced, in which:

T_1 = temperature of the exhaust steam in degrees Fahr.

T_2 = temperature of the feed water in degrees Fahr.

t = mean temperature of the circulating water, or mean between temperatures of injection and discharge water. (See *Engineering*, Vol. XX, p. 449.)

L = latent heat of the steam of temperature T_1.

k = perfect conductivity of metal for a range of 1° F. for one square foot. (See Table III.)

c = fraction denoting the efficiency of the condensing surface.

q = rate of conductivity corresponding to a variable range of temperature $T-t$, and surface of rate ds.

W = pounds of steam condensed per hour.

S = square feet of condensing surface.

Then the units of heat transmitted per hour to the circulating water are—

$$\int q \, ds = W \left\{ L + T_1 - T_2 \right\} \tag{1}$$

Now we may suppose a unit of weight of steam at a sensible temperature T_1 and latent heat L to impinge upon the surface of the tubes, which are kept practically at a constant temperature t by the circulating water. The units L will be transmitted gradually to the circulating water while the temperature of the steam remains at T_1; so that finally the units L will all have been communicated to the circulating water and the steam will have been condensed to water at T_1. The range of temperature during this performance was

$$T_1 - t.$$

Now this water at T_1 will, by contact with the tubes of constant temperature t, be changed gradually to T_2, so that the absolute range will be from

$$(T_1 - t) \quad \text{to} \quad (T_2 - t),$$

and at any instant while it is on an elementary surface of rate ds the range is

$$T - t;$$

hence, for the water,

$$q = ck\,(T - t),$$

and for the steam, or rather for the units L in it,

$$q = ck\,(T_1 - t).$$

Therefore, transforming equation (1), we have

$$S = \frac{W}{ck} \left\{ \frac{L}{T_1 - t} + \int_{T_2}^{T_1} \frac{dT}{T - t} \right\} \tag{2}$$

or

$$S = \frac{W}{ck} \left\{ \frac{L}{T_1 - t} + \log_\epsilon \left(\frac{T_1 - t}{T_2 - t} \right) \right\} \tag{3}$$

From results of the performances of five United States naval surface condensers (see Table II) c is found to be 0.147676 where the main engine works the pumps.

The writer regrets he has no more data at hand with which to extend Table II and thereby attain more practical values for c, both

when the main engine works the pumps and when they are independent. It may, however, be noted that the amount of surface can be reduced about 10 per cent. when independent pumps are used.

Substituting the value of ck we have

$$(4) \qquad S = \frac{W}{82.2252}\left\{\frac{L}{T_1 - t} + \text{hyp. log}\left(\frac{T_1 - t}{T_2 - t}\right)\right\}$$

which is based on successful practice and not entirely on laboratory results. It shows the relation between the condensing surface and the various functions mentioned in the first paragraph.

The designer of a surface condenser after finding his required I.H.P., assumes that a certain number of pounds of steam per hour will be required per I.H.P., and that it will be sent to the condenser at a certain pressure; also that the injection, discharge and feed waters will have certain definite temperatures. He determines this weight of steam referred to from results of similar engines known to be economical; then use formula (4) above.

The efficiency of a condensing surface is found by solving equation (3) for c.

An application of formula (4) may be made by assuming the temperatures of injection, discharge and feed to be 85°, 95° and 150° F. respectively, and the pressure of the exhaust steam that due to the most economical ratio of expansion, as determined by Mr. C. E. Emery, viz. $\frac{1}{0.19}$ when the initial pressure is 80 lbs. gauge. Then $T_1 = 222.5$; $L = 958.68$; and $t = 90$. The United States steamers Galena, Quinnebaug and Miantonomoh have each steam-jacketed, two-cylinder, compound engines using steam of 80 lbs. gauge and may have the above temperatures under the most unfavorable conditions. The condensing surface of each is shown, by use of formula (4), in the following table, viz.:

Vessel.	Designed I.H.P.	Condensing surface in square feet. By (4) assuming 20 lbs. steam per I.H.P. per hour.	By (4) assuming 25 lbs. of steam per I.H.P. per hour.	Actual.	Pumps.
Galena	1100	2146.0	2682.5	3560.00	Worked by main eng.
Quinnebaug ...	1100	2146.0	2682.5	2300.00	do.
Miantonomoh.	1600	3122.4	3903.0	4225.19	Independent.

On account of the Miantonomoh having independent pumps her surface may be about 10 per cent. smaller than computed above, as the circulation can be greatly improved. The condensing surface of the Galena is 1.55 times that of the Quinnebaug, while all the other conditions are identical; and as good results are now obtained with the smaller surface of the latter as with the large surface of the former.

TABLE I.—Compiled from King's *War Ships of the World*, *Journal of the Franklin Institute*, Isherwood's *Experimental Researches*, *Engineering* and *Engineer*.

Name of Vessel.	I. H. P. developed on full-power trial.	I. H. P. Designed.	Square feet of Condensing Surface.	Ratio of Condensing Surface to designed I. H. P.	Vacuum.	Remarks.	
						Type of Engines.	Pumps.
H. M. S. Devastation	6637	6650	13420	2.02	.....	Simple trunk.	Worked by main engines.
Dreadnought	8216	8000	16500	2.06	27	3-cyl. compound.......	Independent circulating.
Inflexible...........	8407	8000	16000	2.00	.....	do.	do.
Alexandra..........	8600	8000	16500	2.06	.....	do.	do.
Téméraire	7700	7000	16500	2.36	28	2-cyl. compound.......	do.
Shannon	3540	.....	8000	2.26	.....	Tandem compound....	do.
Superb.............	7430	.....	16500	2.22	26½	Simple	do.
Raleigh	6157	6000	12000	2.00	27	do.	do.
Rover...............	4963	4750	9500	2.00	28	3-cyl. compound.......	do.
Iris..................	7556	7000	14000	2.00	27	Tandem 2-cyl. comp'd	do.
Neptune	....	8500	22733	2.67	.....	....	....
Sirius...............	2325	.....	4200	1.80	.....	....	....
Italian C. Colombo....	3782	4000	5000	1.25	.....	Penn's 3-cyl. comp'd..	do.
U. S. S. Quinnebaug.	1103	1100	2300	2.09	19*	2-cyl. compound......	Worked by main engines.
Galena...............	940	1100	3560	3.23	25	do.	do.
Wyoming.............	....	1000	3000	3.00	.....	Simple................	do.
Eutaw	1468.64	.....	2293	1.564	27½	do.	do.
Mackinaw	668	.....	2293	3.43	26	do.	do.
Chippewa	407.2	.....	1512.5	3.385	27½	do.	do.
Alarm	412.8	.....	1688.5	4.09	23⅓	Tandem compound....	All independent.
Despatch	402.7	.....	1164.5	2.891	25½	Simple................	Independent circulating.
Yacht Leila..........	149.94	.....	50.29	0.335	25.6	2-cyl. compound.......	No circulating pump.
Anthracite	67.7	.....	422	6.23	26¾	Perkins' triple exp'n..	Worked by main engines.
S. S. Claremont.......	446	.....	650	1.46	27	Triple exp'n, 2 cranks	do.
Leerdam.......... ..	1250	1100	3150	2.86	.....	2-cyl. compound	Independent circulating.
Moor	....	4536	5490	1.21	.....	....	....
Assyrian Monarch..	2400	.....	5000	2.08	28	....	....
Inchrhona	1327	.....	1900	1.43	26½	....	....

* Vacuum 27, since changes were made in condenser design.

TABLE II.—Showing the Efficiency of the Condensing Surface in a Condenser.

Vessel.	W.	S.	L.	T_1.	T_2.	t.	k. (See Table III.)	ck.	c.	Weight.	Weight × ck.	Weight × c.	Vacuum.	Date.	Remarks.
U. S. S. Galena*	15457.44	3560	971.15	204	118	88	556.832	29.66	0.053266	1	29.66	0.053266	24	July 24, 1882.	Turning Trial.
Quinnebaug...	22029.5	2300	976.06	197.8	135	60	556.832	73.56	0.13219	2	147.12	0.26438	19†	Dec. 6, 1878.	Trial Trip.
Chippewa.....	19958.9	1512.5	945.60	241	110	80	556.832	99.68	0.17902	4	398.72	0.71608	27½	Sept., 1862.	Isherwood's *Exp. Res.*
Eutaw‡	36259	2293	941.50	246.8	100	57.5	556.832	102.25	0.18363	4	409.00	0.73452	27½	Sept., 1863.	do.
Mackinaw......	15173	2293	963.62	216	105	75.2	556.832	55.551	0.09974	3	166.653	0.29922	26	April 6, 1864.	do.
Probable values								82.2252	0.147676						

* 0.9 boiler power. † Vacuum 27, since changes were made in condenser design. ‡ Strong forced draught.

TABLE III.—From Shock's *Steam Boilers*, page 58.

Metal.	Thermal conductivity in terms of heat units transmitted per hour through ONE SQUARE FOOT of material for a difference of temperature of 1° Fahr.	Relative Thermal Conductivity.
Copper.	642.543	1.000000
Brass.	556.832	0.866607
Wrought Iron.	373.625	0.581478
Cast Iron.	315.741	0.491393

REVIEWS.

NAUTISCHE TAFELN DER K. K. KRIEGSMARINE. Pola, 1882.*

These tables are published by the Hydrographic Office of the Austrian Navy. Nearly all of the tables have been newly computed, and all of them have undergone several critical examinations. Nevertheless, the hydrographer begs that any errors in the tables be brought to the notice of the Hydrographic Office. While some of the tables are inferior to those in Bowditch (revised edition, 1881), others are to be commended for greater compactness, better arrangement, or a nearer approach to accuracy. Tables 3, 10, 18, 19, 41, 44 are better as given in Bowditch. The following Austrian tables are to be commended (Austrian in Roman, Bowditch in Arabic) as compared to corresponding tables in Bowditch: II, 2; VII, 43; VIII, 42; XVI, 26_B; XXV, 40; XXX, 6; XXXI, 20 and 21; XXXIII, 16; XXXVIII, 8 and 9; XXXIX, 7.

The Austrian tables contain the following not in Bowditch:

IX. Log. sine and tangent for very small angles; from 1″ to 1°, second by second; from 1° to 6° for ten to twenty seconds.

XII. Natural tangents and co-tangents.

XVIII. Limit of hour angle for determining the latitude from an altitude where 1^m of hour angle should not give more than 2′ error in latitude.

XIX. Length of arc for every degree, minute and second ($r = 1$).

XXIII. From two observed altitudes to reduce the higher altitude to the meridian, the true time of observation being known.

XXIV. Correction to apparent time of sunset and sunrise (upper limb) for dip, refraction, parallax, and semi-diameter. Height of eye, 5 meters.

XXVIII. Dip to 16 meters for every 0.2 meter.

XXXV. Hours, minutes and seconds in decimals of a day for each .01 day.

XXXVI. Correction to sun's observed altitude for dip, refraction, parallax, and semi-diameter. Arguments: sun's observed altitude, dip from 1 to 12 meters, semi-diameter 16′ 00″ with correction to semi-diameter for each half-month.

XL. Comparison and conversion of different barometric and thermometric scales.

XLV. Measures and weights used by different nations.

* Nautische Tafeln der K. K. Kriegsmarine. Auf anordnung des K. K. Reichs-Kriegs-Ministeriums (Marine-Section) zusammengestellt und herausgegeben vom Hydrographischen Amte der K. K. Kriegsmarine. Pola, 1882.

ALMANACH FÜR DIE K. K. KRIEGSMARINE. 1883.*

This is a convenient hand-book for officers, with reference tables and data for which we are obliged to go either to foreign sources or to bulky volumes—seldom at hand when wanted.

The Almanach, besides giving the calendar, a list of the living members of the royal family, postal tariff and money table for the world, is divided into five parts.

Part I. *A.* Nautical signs and tables, navigation formulæ. *B.* System of electrical measurements. *C.* Mass, weight, and reduction tables of all nations.

Part II. Description of the artillery, kind, weight, power, &c., of various naval powers.

Part III. Navy list of all nations.

Part IV. Pay and allowances, under any possible contingency, for all ranks and grades in the Austrian Navy.

Part V. Austrian Navy register.

*Almanach für die K. K. Kriegsmarine, 1883. Mit Genehmigung des K. K. Reichs-Kriegs-Ministeriums (Marine-Section) herausgegeben von der Redaction der "Mittheilungen aus dem Gebiete des Seewesens," III Jahrgang. Pola. In commission bei Gerold and Comp. Wien.

PROFESSIONAL NOTES.

THE RELATIONS BETWEEN THE SIZE, SPEED, AND POWER OF MARINE ENGINES.

By Richard Sennett, Chief Engineer Royal Navy, Memb. Inst. M. E., &c.

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I need scarcely remind the members of this Institution that the relations between the size, speed, and power of marine steam-engines are not absolute and unchangeable, but that they have been continuously varying during the progress of steam navigation. In fact, we may say that advance in marine engineering has resulted from, and been marked by, the modifications made from time to time in these relations.

The elements on which the power of any steam engine depends are the dimensions of the cylinder, the speed at which the piston moves, and the pressure of steam employed. In general terms the power may be taken to vary as the *size* × *speed* × *pressure*. It will be seen from this that the relations between the size, speed and power are directly affected by the pressure of steam at which the engine is worked.

One of the most interesting and remarkable features in the progress of steam navigation has been the successive increments in the working pressures of steam used. The rate of increase may be roughly sketched as follows:—In the few steamships that existed prior to the year 1840, the usual working pressure was 4 or 5 lbs. per square inch. Between 1840–50 tubular boilers were substituted for the old flue boilers, and the working pressures were from 10 to 15 lbs. per square inch. From 1850 to 1860 the ordinary working pressure was 20 lbs. per square inch. Between 1860–70 surface condensing engines became general for marine purposes, and were worked, as a rule, with steam of 30 lbs. pressure. The introduction of surface condensation, by which system the boilers are fed with fresh water, enabled high steam pressures to be carried with safety in marine boilers; and since 1870 compound engines have become almost universal for steamships. These were at first worked at 60 lbs. pressure. The pressures have gradually increased from 60 to 80, 90, 100, and in some recent examples to 125 and 150 lbs. per square inch. The ordinary working steam pressure in marine boilers at the present day may be taken at from 90 to 100 lbs. per square inch, and it is probable that still higher pressures may be used before long.

The increase in the working pressure of steam has produced two effects :—

1. Reduction of the expenditure of coal ; which is perhaps the more important, for this, and this alone, has rendered steam navigation, for long voyages, possible.

2. Reduction of the weight and space occupied by the machinery ; this, from many points of view, especially for war-ships, is scarcely, if at all, less important than the reduction in the coal stowage.

These two divisions are so closely allied that it is somewhat difficult to deal with one without referring to the other. The subject of economy of fuel, however, important as it is, does not exactly come within the scope of the present paper; and I therefore propose to confine attention, as closely as possible, to the consideration of the reductions in size and weight of engines of a given power that have been made, from time to time, by increasing the working pressures of steam and speeds of piston.

This is one of the principal problems with which marine engineers have to deal, and much progress has been made in its solution during recent years, and in connection with the machinery of ships intended for purposes of war. In war-ships, reduction of the space and weight required for the machinery may, in many cases, be of even more importance than reduction of coal expenditure. Although it is desirable that war-ships should be self-supporting for as long periods as possible, they are not often required to steam long distances at high speed, which is the normal condition of service in the mercantile marine, in which, therefore, economy of coal consumption is, of necessity, the first consideration.

In most cases, however, we shall find that the same measures that have produced economy of fuel, have also enabled the space and weight required for the engines to be reduced at the same time, particularly at the beginning of the upward rise in the steam pressures. It is, however, possible that we may reach a point at which the increase in working pressure, though increasing the economy of fuel, will not permit of any reduction in the space and weight required for the machinery, so that the only gain in this direction would be that due to the reduced quantity of coal required to be carried. It is also conceivable that, by-and-by, a point may be reached at which further increase of pressure would not result practically in any reduction either in space or weight required for the machinery (including bunkers), or in the coal expenditure. I think, however, we are scarcely within measurable distance of that position yet.

The effect of the increase in the working steam pressure is to enable a given power to be obtained with a cylinder of smaller diameter, and thus to reduce the size and weight of the engines. The volumes of the steam-pipes and of the steam-spaces in the boilers may also be reduced, because the *relative volume* of the steam is decreased, that is to say, a given *weight* of steam at the higher pressures occupies less space than at the lower pressures. For example, at a pressure of 5 lbs. above the atmosphere 1 lb. of steam would occupy 19.6 cubic feet, at 20 lbs. pressure 11.6 cubic feet, at 60 lbs. 5.7 cubic feet, and at 100 lbs. pressure only 3.8 cubic feet. The boilers, steam-pipes, &c., can be further

reduced, in consequence of the collateral advantage gained by the use of high pressure steam, viz. that *less weight* per I.H.P. is required, in consequence of the more economical working of the engines. All these parts may therefore be reduced not only from the decreased *relative volume* of the steam, but also because the total weight of steam required to be generated is likewise diminished.

So far we have referred only to the reduction in size and weight due to the increase in the working pressures of steam. This has, however, been accompanied by a considerable increase in the speeds at which the pistons of marine engines are worked, which has tended still further to reduce the weight and dimensions of the machinery. This increase of speed has, of course, to some extent resulted from the use of higher pressures; but, I think, it must be largely attributed to improvements in design and in the details of practical workmanship. In the earlier engines it was not considered safe to work the pistons at a much higher speed than about 200 feet per minute. From an old machinery specification, dated 1845, I extract the following:

The speed of piston for

ft.	in.					
4	0	stroke	is not	to exceed	196	feet per minute.
4	6	"	"	"	204	"
5	0	"	"	"	210	"
5	6	"	"	"	216	"
6	0	"	"	"	222	"
6	6	"	"	"	226	"
7	0	"	"	"	231	"
7	6	"	"	"	236	"
8	0	"	"	"	240	"

In the modern marine engines of large power the piston speeds are often as high as from 600 to 700 feet per minute, and every effort is being made, by the use of improved workmanship and appliances, to increase the piston speed, with safety, to as great an extent as possible.

The relations between the size, speed, and power of marine engines may, perhaps, be most clearly illustrated by giving a brief sketch of the changes that have been introduced from time to time. In this comparison I have confined attention to the progress made in ships of the Royal Navy, for which the information is more complete and available than for the mercantile marine; and this will probably possess the greater interest for the members of this Institution. I think, too, we may safely state that the machinery for ships-of-war has, in all stages of the progress of steam navigation, represented the most perfect and complete type of marine engine of the day. It will, I think, be admitted that the design of the machinery for ships of the Royal Navy has not only kept abreast of the times, but that, in many instances, it has taken the lead and initiated improvements which have considerably advanced marine engineering.

The information that can now be obtained about the earlier vessels is much less complete and exact than about the later vessels, for it is only within a compara-

tively recent period that the importance of keeping full and accurate records of all the particulars and performances of steam-vessels has been fully recognized. I have, however, endeavored to make the comparison as full and fair as possible, and although it must be considered to some extent incomplete and approximate, I think a few useful lessons may be learnt from it. The *size* of the engine has been represented by two particulars, viz. the cubic capacity of the cylinders, and the total weight of the machinery; the former giving a measure of the dimensions of the engines themselves, independent of the boilers and appliances.

The propeller used in all the earlier steamships was invariably the paddle-wheel, and the type of engine generally employed was that known as the *side-lever* engine, which may be regarded as the marine counterpart of the beam-engine so universally used at that time for land purposes. This engine possessed the advantages of having the pistons and rods, to a great extent, balanced by the pumps and rods and connecting-rods, so that the piston was nearly in equilibrium in all positions. The great length of connecting-rod was also favorable for the transmission of the power to the crank. The engine was, however, very heavy, and occupied much space for the power developed. The boilers that supplied steam to the earlier engines were those known technically as *flue boilers*, in which the heating surface consisted of the exterior surface of a winding flue that conveyed the products of combustion from the furnaces to the funnel. These boilers were excessively heavy and cumbrous, and suitable only for very low pressures of steam.

As an illustration of this type we will take the Rhadamanthus, which ship was fitted with side-lever engines and flue boilers, by Messrs. Maudslay, in 1832. The nominal horse-power was 220, but the engines were capable of being worked up to about 400 I.H.P., or 1.8 times the nominal power. The load on the safety valves was 4 lbs. per square inch, and the speed of piston, at full power, 175 feet per minute. The cubical capacity of the cylinders was 168 cubic feet, so that only 2.38 I.H.P. were developed per cubic foot of cylinder. The total weight of the machinery was 275 tons, 1.45 I.H.P. being obtained per ton of weight.

The next step was the introduction of *tubular* boilers, in which a series of small tubes was substituted for the large winding flue; the boilers were thus made lighter and more compact, and the working pressures of steam were increased. Attempts were also made to reduce the space and weight required for the engines by the substitution of direct-acting for side-lever engines. There were many varieties of this type, one of the earliest being the well-known double-cylinder engine, fitted by Messrs. Maudslay in the Terrible and several other vessels. This engine consisted of two cylinders side by side, the piston-rods from the two cylinders being attached to a single crosshead. In order to get sufficient length of connecting-rod, the crosshead was of peculiar form and passed down between the two cylinders, having a journal at its lower end, on which one end of the connecting-rod worked, the other end being attached to the crank-pin. The engines of the Terrible were completed in 1845, and were of 800 N.H.P. The I.H.P. was 1905, or 2.38 times the nominal

e.	Cubic capa-city.
n.	cub. ft
	168
	904
	393
	904
	440
	268
	396
	230
	293
	268
	220
	293
	369
	220
	293
	474
	445
	402
	514
	382
	684
	474
	295
	388
	419
	303
	339
	339
	455
	453
	490
	143
	707
	795
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Ship	Date	Maker.	Description. Engines	Description. Boilers	Load per square inch on safety valves	N.H.P.	I. H. P.	I. H. P. / N.H. P.	Revolutions per minute	Cylinders No	Cylinders Diameter.	Cylinders Stroke	Cylinders Cubic capacity.	Pistons Speed per min'te	Pistons Volume swept out per minute.	Weight Engines.	Weight Propellers and shafting	Weight Boilers and water.	Weight Total.	Weight per I. H. P. Engines.	Weight per I. H. P. Propellers and shafting.	Weight per I. H. P. Boilers and water.	Weight per I. H. P. Total.	I. H. P. per Cubic foot of cylind'r	I. H. P. per Cubic foot swept out by piston	I. H. P. per Ton of weight
					lbs						ins	ft in.	cub. ft.	feet.	cubic ft	tons	tons.	tons.	tons	lbs.	lbs	lbs	lbs.			
Rhadamanthus	1832	Maudslay..	Side-lever	Flue....	4	220	400	1.8	17.5	2	55½	5 0	168	175	5880				275				1550	2.38	0.068	1.45
Retribution	1842	"	4-cylinder, vertical	"	6	800	1600	2	13	4	72	8 0	904	218	23,504				700				980	1.77	0.068	2.3
Gladiator	1845	Ravenhill	Vertical, direct ...	Tubular	11	430	1023	2.38	15.5	2	79½	5 9	303	178	12,174	165	48	144	357	361	103	315	781	2.6	0.084	2.87
Terrible	1845	Maudslay.	4-cylinder, vertical.	"	9	800	1905	2.38	15	4	72	8 0	901	210	27,108	230	117	260	607	272	139	306	711	2.1	0.07	3.14
Sphinx	1846	Penn	Oscillating	"	7	500	1180	2.36	16	2	82	6 0	440	192	14,083	117	43	135	295	222	82	256	580	2.68	0.08	4.0
Buzzard	1850	Ravenhill.	"	"	20	300	834	2.78	20.5	2	64	6 0	268	216	11,008	67	31	145	243	180	93	380	653	3.104	0.076	3.43
Magicienne	1850	Penn	"	"	14	400	1300	3.25	20.5	2	72	7 0	396	287	16,230	95	41	139	275	164	70	210	474	3.28	0.08	4.72
Himalaya	1854	Penn	Trunk......	Lamb's patent flue.	15	700	2046	2.92	58	2	=77⅜	3 6	230	392	25,766	121	17	257	425	133	50	282	465	8.80	0.079	4.82
Doris	1857	"	"	Rectangular, tubular	20	800	3005	3.75	54	2	=82	4 0	203	432	31,644	143	60	341	544	106	45	254	405	10.25	0.095	5.52
Galatea	1859	"	"	" "	22	800	3052	3.82	56	2	=82	3 8	268	410	30,023	139	65	350	554	102	48	257	407	11.38	0.101	5.51
Immortalité	1859	Maudslay.	Return connect'g-rod	" "	20	600	2390	3.98	55	2	76	3 6	220	385	24,201	135	50	244	429	127	47	228	402	10.86	0.098	5.57
Revenge	1859	"	"	" "	20	800	2548	3.18	52	2	82	4 0	293	417	30,571	180	62	300	542	158	54	264	476	8.68	0.083	4.7
Victoria	1860	"	"	" "	22	1000	4403	4.4	58.4	2	92	4 0	369	467	43,120	230	76	416	722	117	39	212	368	11.93	0.102	6.1
Undaunted	1861	Ravenhill	"	" "	21.5	600	2210	3.70	58	2	76	3 6	220	406	25,520	119	47	225	391	116	40	223	387	10.27	0.088	5.78
Valiant	1861	Maudslay	"	" "	25	800	3348	4.18	59	2	82	4 4	294	475	34,831	191	48	379	618	128	32	253	413	11.41	0.096	6.42
Black Prince	1861	Penn	Trunk.....	" "	21.5	1250	5571	4.45	54.75	2	=104⅛	4 0	474	438	51,903	240	97	550	887	96	38	221	355	11.75	0.107	6.28
Agincourt	1864	Maudslay..	Return connect'g-rod	" "	27	1350	5913	4.38	53	2	101	4 0	445	426	47,394	291	115	564	970	110	43	213	366	11.1	0.121	6.09
Ocean	1864	"	"	" "	22	1000	4243	4.24	58	2	96	4 0	402	464	46,646	215	78	447	740	113	41	236	390	10.55	0.09	5.73
Northumberland	1866	Penn.	Trunk	" "	25	1350	6545	4.84	47.6	2	=104⅛	4 4	514	414	48,954	316	98	629	1043	108	33	215	356	12.72	0.133	6.27
Crocodile	1867	Humphrys	Horizontal, direct ..	" "	30	700	4044	5.77	63	2	96	3 4	382	472	48,039	223	85	303	611	123	47	168	338	10.58	0.084	6.6
Hercules	1868	Penn	Trunk ..	" "	30	1200	8529	7.10	71	2	=118	4 6	684	639	97,128	415	99	547	1091	117	26	144	287	12.47	0.088	7.8
Inconstant	1868	"	"	" "	30		7364		74.5	2	=104⅛	4 6	474	596	70,584	347	88	550	985	106	26	167	299	15.53	0.104	7.5
Active	1869	Humphrys	Horizontal, direct.	" "	30	600	4130	6.88	74	2	88	3 6	295	518	43,719	173	55	271	499	94	30	147	271	14.0	0.094	8.28
Audacious (twin screw)	1869	Ravenhill.	Return connect'g-rod	" "	30	800	4834	6.04	75	4	77	3 0	388	451	58,285	229	61	335	625	100	28	160	294	12.46	0.08	7.6
Swiftsure	1870	Maudslay.	"	" "	30	800	4913	6.14	68	2	98	4 0	419	547	57,294	240	60	334	660	121	27	152	300	11.7	0.09	7.4
Volage	1869	Penn.	Trunk	" "	30	600	4530	7.55	79	2	=86¼	3 9	303	592	47,934	216	49	293	558	107	24	145	276	15.0	0.095	8.1
Invincible (twin screw)	1870	Napier	Return connect'g-rod	" "	30	800	5180	6.48	81.6	4	72	3 0	339	490	55,894	258	59	354	671	112	25	153	290	15.26	0.09	7.7
Vanguard "	1870	Laird.	"	" "	30	800	5384	6.73	74.9	4	72	3 0	339	441	50,128	306	72	336	714	127	30	140	297	15.8	0.107	7.3
Devastation "	1871	Penn	Trunk	" "	30		6637	..	76.8	4	=80	3 3	455	499	69,801	334	92	456	882	113	31	154	298	14.8	0.09	7.5
Thunderer "	1872	Humphrys	Horizontal, direct	" "	30		6271		77.5	4	77	3 6	453	542	70,173	370	101	504	975	132	33	180	345	13.9	0.080	6.4
Raleigh	1873	"	Return connect'g-rod	" "	30	800	6157	7.69	74	2	100	4 6	490	665	72,496	336	88	527	951	122	32	192	346	12.55	0.08	6.5
Amethyst	1872	Rennie	Horizontal, comp'd..	High, cylindrical.	60	..	2310		98.5	2	1 No. 55½; 1 " 97¾	2 0	143	542	28,184	130	27	102	310	126	26	157	309	16.15	0.082	7.24
Alexandra	1875	Humphrys	Vertical, compound	" "	60		8498		66	6	2 No. 70; 4 " 90	4 0	707	528	93,324	497	167	656	1320	131	44	173	348	12.02	0.09	6.4
Dreadnought	1875	"	" "	" "	60		8206		67.13	6	2 No. 66; 4 " 90	4 6	795	604	106,739	528	128	705	1361	144	35	192	371	10.32	0.077	6.0
Bacchante	1876	Rennie	Horizontal, comp'd.	" "	70		5413		76	3	1 No. 73; 2 " 92	4 0	369	608	56,179	301	60	482	843	125	28	200	353	14.7	0.096	6.4
Inflexible	1876	Elder	Vertical, compound	" "	60		8485		71.5	6	2 No. 70; 4 " 90	4 0	707	572	101,100	532	112	752	1396	140	30	198	368	12.0	0.084	6.07
Shannon	1876	Laird	Horizontal, comp'd.	" "	70		3538		65.5	4	2 No. 44; 2 " 85	4 0	315	524	41,291	242	68	334	644	153	43	211	407	11.2	0.086	5.48
Temeraire	1876	Humphrys	Vertical, compound	" "	80		7696		78.75	4	2 No. 70; 2 " 114	3 10	537	604	84,577	426	113	664	1203	124	33	193	350	14.3	0.091	6.4
Euryalus	1877	Ravenhill.	Horizontal, comp'd.	" "	70		5250		71	3	1 No. 73; 2 " 93½	4 0	380	568	53,960	353	65	483	901	150	28	206	384	13.8	0.097	5.82
Iris	1877	Maudslay	" "	" "	65		7714		97	8	4 No. 41; 4 " 75	3 0	368	582	71,411	382	65	573	1020	111	19	166	296	20.96	0.108	7.56
Nelson	1877	Elder	Vertical, compound	" "	60		6246		80	4	2 No. 60; 2 " 104	3 6	413	560	66,080	293	107	556	956	105	38	200	343	15.12	0.094	6.5
Northampton	1877	Penn	Vertical, composite	" "	60		6010		84	6	54	3 3	310	546	52,098	464	82	588	1074	150	31	219	400	10.38	0.115	5.5
Carysfort	1878	Elder......	Horizontal, comp'd.	Low, cylindrical	60		2300		107	3	1 No. 46; 2 " 64	2 9	123	588	26,294	127	31	214	372	124	31	208	363	18.7	0.087	6.2
Cleopatra	1878	Humphrys	" "	" "	60		2611		107.9	4	2 No. 36; 2 " 64	2 6	111.5	540	24,062	121	35	201	357	104	30	172	306	23.4	0.109	7.3
Agamemnon	1880	Penn	Vertical, composite	High, cylindrical	60		6000		86	6	54	3 3	310	559	53,329	433	105	598	1136	161	40	223	424	19.3	0.112	5.28
Polyphemus	1882	Humphrys	Horizontal, comp'd..	Locomotive, cylin'cal	126		5500		120	4	2 No. 38; 2 " 64	3 3	145	780	34,866	183	46	209	438	75	18	85	178	38.0	0.158	12.56
Satellite (without blast)	1882	"	" "	Low, cylindrical.	90		1115		98.5	2	1 No. 36; " 62	2 6	52	492	10,244	55	15	110	180	110	30	211	351	21.44	0.108	6.19
[illegible]	1880	Barrow Co.	" "	" "	60		452		126	2	1 No. 28; 1 " 48	1 6	19	378	4788	27	6	41	74	134	30	203	367	23.8	0.094	6.1
First class torpedo-boat	1880	Thornycroft	Vertical, comp'd. ...	Locomotive, cylin'cal	120		460		438	2	1 No. 12⅜; 1 " 20⅞	1 0	2.4	876	2102	4⅜	¾	7¼	12⅜	20.7	3.65	35.3	59.65	191.6	0.210	37.66

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power. The pressure of steam in the boilers was 9 lbs. per square inch, the speed of piston 240 feet per minute, and the total weight of the machinery 607 tons. In these engines 2.1 I.H.P. were developed per cubic foot of cylinder, and 3.14 I.H.P. per ton of weight.

The simplest and most compact form of engine for paddle-wheels was attained by the introduction of the *oscillating engine*, which was adopted and perfected by the late eminent marine engineer, Mr. John Penn, with whose name this type is generally associated, though it was also used by other makers. In this engine the connecting-rod is dispensed with, and the piston-rod is connected directly to the crank-pin. The cylinders oscillate upon hollow axes or trunnions, through which the steam is admitted to, or exhausted from, the cylinders, so that the piston-rod may accommodate itself to the rotatory motion of the crank. As an example of this type we will take the Magicienne, which ship was engined by Messrs. Penn in 1850. The pressure of steam in the boilers was 14 lbs. per square inch, piston speed 287 feet per minute, I.H.P. 1300, and total weight of machinery 275 tons. In this engine 3.28 I.H.P. were developed per cubic foot of cylinder, and 4.72 I.H.P. per ton of weight.

The introduction of the screw-propeller for the propulsion of ships was the most important step in the progress of steam navigation. In order to obtain the same speed of ship, it was necessary to drive the screw-propeller at a much greater number of revolutions than the paddle-wheel. When the screw was first introduced it was not considered practicable to drive the pistons at a sufficiently high rate of speed to enable the engine-shaft to be connected directly to the propeller shafting, and the earlier engines used for working screw-propellers were *geared*, so that the screw-shaft was caused to revolve more rapidly than the engine-shaft. A large spur-wheel keyed on the end of the crank-shaft of the engine worked into a pinion on the screw-propeller shafting, so that the speed of the engine-shaft might be multiplied on the screw-shaft as many times as might be required. The pressures of steam and speeds of piston employed with these *geared engines* were practically the same as those of the paddle-wheel engines that immediately preceded them, so that while it is interesting to note this step, it is not necessary to discuss it further.

Soon after the introduction of the screw-propeller, improvements in workmanship, appliances, and mechanical details so far advanced, that the speeds, both of piston and of revolution, could be sufficiently increased to enable the crank-shaft to be coupled directly to the screw shafting. The boilers for these screw engines were made sufficiently strong to carry higher steam pressures, and the increase both of the pressure of steam used, and of the speed at which the pistons were worked, led to a very considerable increase in the power that could be obtained within a given weight and space, and gave a great impetus to the advance of marine engineering. It is quite certain that the very powerful engines which are now so general would have been altogether impossible had not the screw-propeller superseded the paddle-wheel. During the period 1850–60 a number of wooden frigates and corvettes, fitted with horizontal screw engines, were added to the Navy. The engines were placed horizontally, in order to keep them below the level of the water-line, so as to be protected

from the effect of shot and shell. The pressure of steam used was about 20 lbs. per square inch, and, in the majority of the better examples, the speed of piston was increased to about 400 feet per minute. In a few cases the speeds of piston were still higher than this; the Doris, for example, of 3000 I.H.P., having a piston speed of 432 feet per minute, and the Victoria, of 4400 I.H.P., a piston speed of 467 feet per minute. The engines were all jet condensing, and very little expansion was carried out in the cylinders, so that the consumption of coal for the power obtained was high: this, however, only indirectly affects the point under consideration at present. As the average results of this type, we may take—

I. H. P. developed per cubic foot of cylinder	= 10.0
" " ton of weight	= 5.5

This will be seen to be a very considerable advance from the best examples of the slower moving paddle-wheel engines.

The engines fitted in the earlier ironclads were very similar in design to those just mentioned; but as they were of larger power, and the beam of the ship permitted a considerable increase in the length of stroke, the speeds of piston were somewhat higher, and the average results were rather better than those quoted above; as may be seen by reference to the table appended to this paper.

With the jet injection condensers fitted in the earlier ships, in which the steam was condensed by actual mixing with sea-water, the feed-water was practically as salt as the sea-water itself, and a pressure of from 20 to 25 lbs. per square inch was considered to be the highest that could be safely carried in marine boilers, in consequence of the danger that would result from scale accumulating on the heating surfaces. The general adoption of surface condensation, however, overcame this difficulty, by enabling the boilers to be fed with fresh water. In these condensers the steam is condensed by being brought in contact with the cold surfaces of a series of small tubes, through, or around which, cold sea-water is kept circulating by the agency of a pump. There is, therefore, no admixture with the sea-water, and the fear of overheating from incrustation on the heating surfaces of the boilers is thereby removed. Since the year 1860 this system has become universal for marine purposes, and has rendered high pressures for steam navigation practicable.

When the above system was first introduced, the old flat-sided boilers made to fit the section of the ship were still retained. The form of shell in these boilers is obviously unfit for high pressures, but they were strengthened by fitting additional stays, &c., to enable them to carry working steam pressures of 30 to 35 lbs. per square inch, and the great majority of the war vessels built during the years 1860–70 were fitted with surface condensing engines, worked with steam of this pressure. The piston speeds were also considerably increased, especially in the larger ships, in which a long stroke could be obtained. In fact, during this decade and with this type of machinery, the speed of piston of marine engines reached a point which has only been exceeded in a few ships of recent construction. With this type of engine, the piston speeds

varied from 500 to as high as 665 feet per minute. To promote economy of fuel the cylinders were generally made very large, to allow for a considerable amount of expansion at full power, and the boilers were fitted with superheaters, so that the reduction of weight was not so great as might have been anticipated from the augmentation of the piston speed. In the majority of these engines, between 13 and 14 I. H. P. were developed per cubic foot of cylinder, and about 7½ I. H. P. per ton of weight. In some engines of this class fitted to several of the twin-screw ironclads, the speed of piston barely reached 500 feet per minute, but the other results were as given above.

We now come to the ordinary type of compound engine which has been fitted to nearly all war-ships since 1870, and which may be considered as the general type of marine steam engine of the present day. In these engines the steam from the boilers is only admitted direct to a small cylinder, usually known as the high pressure cylinder, and at the end of the stroke in that cylinder, instead of passing at once to the condenser, the steam enters one or more additional and larger cylinders, in which the expansion is completed; after which the steam passes to the condenser. The boilers are therefore only in direct communication with the high pressure cylinders, and the condensers with the low pressure cylinders.

The working steam pressure in the Royal Navy with this type of engine hitherto has been from 60 to 70 lbs. per square inch. The engines now under construction are designed to be worked with steam of 90 lbs. pressure. As pointed out in the earlier part of this paper, the principal object aimed at in increasing the pressure of steam has been to increase the economy of working, and the change from the ordinary surface condensing engine, with 30 lbs. steam pressure, to the compound engine with 60 lbs. pressure, resulted in a reduction of the coal consumption per I. H. P. of between 30 and 40 per cent.

This step, however, has not been accompanied by a corresponding increase in piston speed, and decrease in dimensions and weight required per I. H. P. In fact, it must be admitted that, although the present type of compound engine is lighter than simple expansion engines worked at the same steam pressure, and with an equal amount of expansion, would be, yet the machinery as a whole is generally heavier than that of the surface condensing engines with flat sided boilers worked with steam of 30 lbs. pressure which immediately preceded them, and the piston speeds are certainly no higher.

The only advantage, therefore, in point of reduction of weight and space that has been gained, as yet, by the introduction of compound engines and high pressure boilers has been the reduction of coal bunker space required. This is most important, but it scarcely comes within the range of the present paper, though intimately connected with it.

I will endeavor to point out the causes of this apparent check in the reduction of weight, &c., and to indicate what appears to be the most probable direction in which advance in the future is likely to take place. As a matter of course, in such a case it is impossible to speak with any degree of confidence; all that can be done is to discuss the several points that push themselves forward, and suggest the most reasonable and probable solution, so far as our present knowledge, experience and judgment will guide us.

The first point that strikes us is the increased weight of the boilers. For example, compare the boilers of the Devastation with those of the Nelson. The engines of both ships developed rather more than 6000 I. H. P. The boilers of the Devastation are flat-sided, pressed to 30 lbs. per square inch, and, including water, weigh only 456 tons. The boilers of the Nelson are cylindrical, pressed to 60 lbs., and weigh 556 tons, including water. In other words, while the Devastation's boilers weigh 154 lbs. per I. H. P., the boilers of the Nelson weigh 200 pounds per I. H. P., or 30 per cent. more. Again, compare the Inflexible with the Hercules, both of which ships have engines of about the same power. The boilers of the Hercules, loaded to 30 lbs. pressure, weigh 547 tons, or 144 lbs. per I. H. P., whilst the cylindrical boilers of the Inflexible weigh 752 tons, or 198 lbs. per I. H. P., which is an increase of 37½ per cent.

This increase of weight may be to some extent attributed to the increased strength necessary to carry the higher steam pressure. This, however, is insufficient to account for all the increase, for, in consequence of the more economical working of the engines, less steam is required to be generated, so that the volumes of the boilers and the areas of heating and grate surface may be made less than in the low-pressure boilers.

The principal cause of the increased weight of the boilers appears to be due to the additional thickness of plate allowed to provide against the effects of corrosion. Many of the earlier boilers, fed with water from surface-condensers, were so rapidly weakened by corrosion that they had to be renewed after having been at work for one commission only. The expense of opening out the ship to do this was so great that it was considered desirable to increase the thickness of the shell plates, to enable the boilers to be kept in the ship, without the necessity of removal, for at least two commissions.

By the introduction of steel plates and more improved systems of management, it is hoped that this difficulty will be to a great extent removed. Steel plates are more uniform in structure and much stronger than iron, so that the scantlings may be reduced for a given strength; and now that the mystery that appeared for some time to enshroud the subject of the corrosion of marine boilers has been dispelled, and the true causes of the action ascertained, it appears probable that a reduction in the *factor of safety* usually employed may be safely made. The great importance of this would result from the increase in the maximum working pressure of steam that could then be carried with the present type of marine boiler.

To illustrate this point, let us consider the case of a cylindrical boiler 10 feet in diameter, the shell of which is made of steel plates ¾ of an inch thick. The tensile strength of these plates is usually specified to be not less than 26, nor more than 30, tons per square inch. Many engineers are desirous of raising the lower limit of strength, and this may be possible before long; but for our present purpose we will take the lower limit of 26 tons, and estimate the difference in the pressures of steam that could be carried by allowing factors of safety of 8 and of 5 respectively. The strength of the joint has been taken as 0.75 of that of the solid plate.

If 8 be taken as the factor of safety, the maximum working stress allowed on the material would be one-eighth of the ultimate stress, or 7280 lbs. per square inch. This would be produced by a working steam pressure of 68 lbs. per square inch. If, however, a factor of safety of 5 were considered to leave a sufficient margin of strength to provide for all contingencies, the maximum working stress on the material would be increased to 11,648 lbs. per square inch, which would permit a working steam pressure of 109 lbs. per square inch to be carried. Further, if we suppose that after four or five years' work the plates were uniformly thinned by corrosion to the extent of $\frac{1}{8}$ of an inch, the factor of safety in the second case, if the original working pressure were retained, would still be 4.167, which is by many engineers considered ample; but if it were deemed desirable to retain the original margin of safety, this could be done by reducing the working pressure to 91 lbs. per square inch.

In estimating the strength of a structure like that of the shell of a boiler there are few disturbing elements, and almost exact calculation can be applied. The strength of the material used may be considered uniform, and with proper supervision during manufacture, inferior workmanship may be prevented. The most uncertain element, hitherto, has been the effect of corrosion and wear and tear, and this has caused a high factor of safety to be generally employed. Now, however, that most of the difficulties attending the boiler-corrosion question have been overcome and the methods of reducing or preventing this action have been satisfactorily ascertained, we may hope that marine boilers may retain their original strength for much longer periods than was formerly the case; and it would therefore appear that the factor of safety used for the shells of the boilers may be reduced with advantage.

The criterion of the relative strengths of the several parts is the strength they respectively possess when the boiler is worn out and unfit for further work. It is the usual practice in the Government dockyards to burst by water pressure, for the sake of experiment, one boiler out of each set condemned, and a mass of very valuable information as to the ultimate condition of the boilers is thereby obtained. I have had, in the course of my duty, to conduct many of these bursting experiments, and, so far as my experience goes, the weakest part has, in every case, proved to be the furnace or combustion chamber, and I think it is quite safe to say that while the present form and dimensions of furnaces and combustion chambers are retained—and there appears to be no tendency to increase the thickness of the plates in these parts—there is no necessity to use a higher factor of safety for the shells than 5. Even with this factor I believe that, when the boilers come to be worn out, the furnaces and combustion chambers will be found to be the weakest parts, notwithstanding the fact that they apparently had a much greater margin of strength than the shells, when new. It must not be forgotten that in these parts the material is weakened to some *unknown* extent by the working and flanging at the fires during manufacture, and when the boilers are under steam, unequal and unknown strains are brought on the material by the expansion resulting from the heat of the furnaces. It is also probable that the material deteriorates from the alternate heating and cooling to which it is exposed; and corrosive action,

if it occurred at all, would probably produce more effect on the heating surfaces than on the shells, which are kept at a much lower and more uniform temperature. The plates in these parts also are generally thinner than in the shells, so that the percentage of loss of strength for a given amount of corrosion would be the greater.

The present type of marine boiler is also a slow and wasteful generator of steam. Even when the draught is forced by means of the steam blast, not more than about 30 lbs. of coal can be burnt per square foot of fire-grate per hour; and only about one-half of this is utilized in evaporating the water. In many cases more than one-half of the heat that the coal is capable of evolving by complete combustion is wasted in various ways. Cylindrical boilers are even more slow and wasteful generators than the old flat-sided boilers.

In order to reduce the weight of the boiler, rapid combustion is necessary. The greater the quantity of coal that can be efficiently burned per square foot of fire-grate per hour, the smaller may the furnaces be made for a given power. In locomotive practice the rate of combustion of coal in ordinary work often reaches as high as from 80 to 100 lbs. per square foot of grate per hour, and in some cases it even exceeds this. This, combined with the smaller amount of water carried, has caused many marine engineers to look to this type as a means of reduction of weight. Mr. Thornycroft, in his fast torpedo-boats, was, I believe, the pioneer in this direction; and he forced the draught by closing the stokeholds and putting them under air pressure. The air is blown into the stokeholds by means of a rotatory fan, and a pressure of air, equal to the weight of from 3 to 6 inches of water, is easily maintained. In some experiments made at Portsmouth, to ascertain the performance of the boiler of a first-class torpedo-boat, it was found that with an air pressure equal to 3 inches of water, 62 lbs. of coal could be burnt per square foot of grate per hour; and when the pressure was raised to 6 inches of water, the rate of combustion was increased to 96 lbs. per square foot of grate per hour.

The only ship of large size in which this plan has been adopted is the torpedo-ram Polyphemus. The machinery of this ship has been constructed by Messrs. Humphrys and Tennant, and every effort has been made to secure lightness. The engines are driven at a high speed, both of piston and of revolution. They are expected when working at full power to make about 120 revolutions per minute and to have a piston speed of about 780 feet per minute. This will give about 38 I.H.P. per cubic foot of cylinder, and 12½ I.H.P. per ton of weight; which is a very great advance on anything yet attained with the ordinary marine engine; and the experiment is most interesting and instructive from both a scientific and practical point of view.

I do not, however, think that the locomotive type of boiler will prove itself suitable for marine purposes generally; though it may be useful in some special cases. The water spaces are too confined for general work at sea, and it would, I think, be found impossible to keep the flat sides of the fire-boxes from bulging and becoming unsafe. The great difficulty that has hitherto been experienced with these boilers, even on the trial trips, which have as yet been the only hard work to which they have been subjected in the service, is the

leakage of the tubes at the fire-box ends. This is equally true both of the torpedo-boats and of the Polyphemus. The cause of this appears to be that the intense heat of the fire being so close to the tube-plate, causes it to expand and compress the ends of the tubes ; so that, when the fires are checked, the contraction of the tube-plate leaves the tubes slack in their holes. The leakage has shown itself, in nearly every case, when the engines were eased after the full-power run, the forced draught being stopped, which reduced the temperature of the fire. The cold air, also, that enters the fire-door when it is opened, impinges directly on the hot tube-plate, without having to pass over such a length of fire as an ordinary marine boiler.

For the present working pressures of steam the ordinary type of marine boiler appears to be the most suitable ; and probably little variation in its form need be made, so far as strength is concerned, for pressures up to about 150 lbs. per square inch. I doubt, however, if it would be wise to much exceed that pressure with the existing type of boiler. If pressures beyond this limit be arrived at, it will be, in my opinion, necessary to adopt some form of boiler built entirely of small tubes, to enable the steam to be generated with confidence and safety. I do not profess to indicate what type of *tubulous* boiler will prove most efficient. Those that have been tried hitherto have not given general satisfaction, but it is probable that the failures have been due more to defects in the details of construction or of management, than to causes inherent to, or inseparable from, the type of boiler. The Herreshoff coil-boiler has proved itself economical and efficient for small boats, and is the lightest type yet constructed for a given power. It is absolutely safe, but whether it is adaptable to larger powers has yet to be proved.

With the present type of marine boiler it is necessary that *artificial draught*, of some kind, should be employed for full-power working, in order to keep the dimensions within moderate limits. Until recently the steam blast was the only means used for forcing the fires. This, however, is a very wasteful way of getting steam, especially with surface-condensing engines. Other methods of forcing the draught are :

1. Fitting an exhausting fan in the funnel.
2. Blowing air into closed ashpits.
3. Blowing jets of air into the base of the funnel.
4. Blowing air into closed stokeholds.

The first plan is obviously unsuitable for ships, for the fan would require to be so large to allow all the products of combustion to pass through it, at a sufficiently high velocity, that the apparatus would be too cumbrous and unwieldy.

The blowing of air into closed ashpits is a very efficient plan, but has the objection that the pressure in the furnaces is greater than that in the stokeholds, so that, unless care be taken when opening the fire doors, accidents are liable to occur. With artificial stoking this plan would probably be found to be both economical and efficient.

The blowing of jets of air into the base of the funnel has been tested by experiment in the French service, and favorably reported on. It is also on trial in

one or two ships belonging to the French navy; but little is known, as yet, of its practical working and efficiency.

The fourth plan, viz. blowing air into closed stokeholds, which has been adopted from the torpedo boats, has found most favor in the Royal Navy. The stokeholds of several of the more recent ships are being arranged and fitted, so that, when working at full power, they may be closed in and kept under air pressure by means of fans.

The Satellite, now completing at Sheerness, is the first ship in which this system has been practically tested. This ship has two independent stokeholds, in each of which there are two boilers. During a three hours' trial made on the 11th instant, with the forward stokehold closed, and kept under an air pressure equal to about one inch of water, the rate of combustion of coal per square foot of grate was raised to 39.4 lbs. per hour, and the I.H.P. developed from the two boilers was 865, or 15.7 I.H.P. per square foot of fire-grate. The average number of revolutions made by the engines per minute was 95.38. On a previous trial made on 3d April, 1882, without artificial draught, the coal burnt per square foot of grate was 18.6 lbs. per hour, and the average I.H.P. developed with four boilers was 1115. The effect of forcing the draught, in this case, enabled the power obtained from a given set of boilers to be increased from 558 to 865, or about 55 per cent.*

With respect to the engine itself, it is probable that a considerable reduction of weight could be made by the more extended application of steel in construction. Forged steel has for some time been largely used for crank and propeller shafting, piston and connecting rods, &c., and the weights of the shafts have been further reduced by making them hollow. Recently, steel castings have been used, in lieu of cast-iron, for several parts of the machinery. The pistons for the engines of the steel cruisers now under construction at Messrs. R. & J. Napier's, Glasgow, are made of cast steel, and their weight is only about one-half the weight necessary for cast-iron pistons of the same diameter. Mild steel castings of great strength and toughness, and free from blowholes, can now be made, and as the processes of manufacture are more fully developed, I think we may look forward to a considerable extension in the application of this material, which will much facilitate the reduction of weight of marine engines. The general use of *wrought* iron or steel framing for marine engines would be very costly, as it would involve a great expenditure for labor, and this system is only likely to be adopted in special cases. If, however, mild steel castings could be made, at moderate price, to supersede iron castings for the various parts, the extra expense due to increased workmanship would be avoided; and it is most probable that the material would be extensively used.

* The steam trials of the Heroine, sister ship to the Satellite, took place at Devonport on the 30th and 31st of May, 1882. On the 30th May, a six hours' run was made with natural draught only, the average power developed with four boilers being 1127 I.H.P. On the following day a three hours' trial was made with the two forward boilers, the fires being forced by the steam blast. There were four blast nozzles used in the funnel, each 7.16 inch diameter, and the average power developed with the two boilers was 695 I.H.P. By the use of the steam jet, therefore, the power of the boilers was increased from 563 to 695, or about 23½ per cent.

The engines of the Nelson, designed by Mr. A. C. Kirk, now the head of the firm of Messrs. R. & J. Napier, of Glasgow, form one of the most complete examples of light wrought iron and steel framing properly and scientifically trussed and secured to the structure of the ship itself that has, as yet, been constructed. The reduction in weight in this case is considerable, the engines only weighing 105 lbs. per I.H.P., while the average weight for engines of the same class, with ordinary cast-iron framing, is 140 lbs. per I.H.P., or 33 per cent. greater. Engines constructed in this manner are, however, necessarily very expensive in manufacture, as much additional labor is involved, and both the workmanship and material employed must be of the highest quality.

It is probable that a saving in weight might be effected if the framing of the engine and of the ship at the section in which the machinery is placed were considered, so far as possible, as one. As a rule the ship is only regarded as a platform to carry the machinery, and the necessary transverse strength is obtained by increasing the weight of the hull, without reference to any strength that might be obtained from the engines. In an able paper by Messrs. Read and Jenkins, of *Lloyd's Register*, "On the Transverse Strains of Iron Merchant Ships," read at the recent meetings of the Institution of Naval Architects, the necessity of providing additional transverse strengthening in the engine and boiler space in steam vessels is clearly pointed out. It would, therefore, be an advantage in the design of the engines, particularly when they are required for war-ships, in which reduction of weight is so important, if the framing could be so arranged and constructed that it would add the necessary additional transverse strength to the section of the ship, instead of being merely a dead weight to be carried by the ship.

This point was emphasized by Mr. F. C. Marshall, of Newcastle, in his paper "On the Marine Engine," read at the meetings of the Institution of Mechanical Engineers, in August, 1881. He says: "Great saving in weight can be effected by careful design, and by judicious selection and adaptation of materials; also by the substitution of trussed framing and a proper mode of securing the engine to the structure of the vessel, in place of the massive cast-iron bed-plates and columns of the ordinary engines of commerce." Also: "The hull and engine should be as much as possible one structure; rigidity in one place and elasticity in others is the cause of most of the accidents so costly to the ship-owner. Under such conditions mass and solidity cease to be virtues, and the sooner their place is taken by careful design, and the use of the smallest weight of material (of the very best kind for the purpose) consistent with thorough efficiency, the better for all concerned."

The reduction in the weight of the engines that could be effected by improved design and workmanship, and the use of stronger material, although most important, does not, of itself, offer so large a scope for improvement as increase of speed, both of piston and of revolution. These have been highly developed by Mr. Thornycroft in the engines of the fast torpedo boats, which at full power make about 440 revolutions per minute and have a piston speed of 880 feet per minute. The total weight of the machinery, including boilers and water, is below 60 lbs. per I.H.P. In the Inflexible the number of revolutions per

minute was 71.5, speed of piston 572 feet per minute, and the total weight of the machinery 368 lbs. per I.H.P. Even in the Polyphemus, in which the nearest approach to the torpedo type of machinery has been attempted, the estimated number of revolutions per minute is 120, speed of piston 780 feet per minute, and total weight of machinery 178 lbs. per I.H.P.

In pursuing this part of the subject we are met with many difficulties, arising, more especially, from the action of the propeller. The generally accepted theory of propulsion is, that the propeller produces a sternward momentum in the water on which it acts, which momentum measures the thrust exerted on the ship. The larger the quantity of water acted on, therefore, the greater will be the thrust. The usual practice has consequently been to make the diameter of the propeller as large as possible. The surface and edgewise friction of these large propellers is very great, and the large mass of water acted on in each revolution entirely precludes the engines being worked at a high speed of revolution, while they are connected direct to the present type of propeller.

From experiments made by the late Mr. Froude, it would appear that considerably more than one-half of the total energy transmitted to the propeller is wasted from various causes. It is, therefore, probable that the design of improved propelling arrangements affords a large field for invention, from which increased economy of propulsion may be reasonably anticipated in future. A large proportion of the loss of efficiency in existing screws arises from the augmented resistance of the ship from the reduction of the pressure of water under the stern produced by the propeller, so that it is very probable that improved propulsion may result, as much from some alteration in the form of ship or in the position of the propeller, as from modification of the form and arrangement of the propeller and fittings.

The substitution of steel blades in lieu of gun-metal or cast-iron, by offering less resistance, will enable the engines to be driven somewhat faster; but a more radical change than this is needed to effect any very substantial reduction in weight and space occupied. It is probable that propellers of smaller diameters, driven at higher speeds, may be used with advantage in many cases. This was clearly shown in the Iris, in which ship, by reducing the diameter of the screws from 18′ 6½″ to 16′ 3½″, the speed of the ship was increased from 16.577 knots to 18.573 knots; the I.H.P. developed by the engines being practically the same in the two trials. It would appear to be very desirable to make further experiments in this direction, especially with twin-screws, to ascertain how far reduction of diameter and increase of speed of revolution may be efficiently carried.

Mr. Thornycroft, in 1879, patented a new form of propeller, by means of which the propelling effect of a screw of given diameter is much increased. The boss is made small at the forward and large at the after end; and behind the propeller is arranged a body of peculiar form furnished with guide plates or blades, for directing the water projected by the propeller. Around the propeller and body a tube case or hollow guide is fitted, which facilitates the flow of water to the propeller, and regulates its discharge sternwards, after having been operated on by the propeller.

Mr. Thornycroft, in his reply on the discussion which followed his paper on torpedo boats, read at the Institution of Civil Engineers, in May, 1881, stated that with his propeller, the diameter of the guide tube being 3 feet, 400 I.H.P. was utilized to the best advantage at a speed of 18 knots. Gunboats whose engines develop about 400 I.H.P. have screws generally about 9 feet in diameter. Mr. Thornycroft also calculated that two propellers, on his principle, similar to the model for the Iris, each 7 feet in diameter, would be sufficient to use 45,000 I.H.P. at 40 knots. Of course, in these cases, the high speed of the ships would allow a full supply of water to the screws, and the statement is not altogether applicable to ships of ordinary form and speed; but it does appear to be probable that by some alteration in the form of ship or propeller, or of both, we may hope to obtain a much greater efficiency of propulsion from propellers of small diameter driven at high speeds. It is in this direction, I think, that a great scope for improvement exists. This, however, cannot be determined theoretically and little can be done until by a careful and extended series of experiments more definite knowledge is obtained of the whole of the conditions of the action and efficiency of propellers. It is very probable that we all have very much to learn, and possibly to unlearn, on this subject.

For the present we shall have to continue to use, with probably slight modifications in size and form, the existing screw-propeller, driven at a comparatively slow speed. It is therefore, I think, worthy of consideration whether or not it would be wise to proceed in the direction of making any material increase in the speed of engines, to reduce their dimensions and weight, until a form of propeller adapted for high speeds of revolution has been devised. If high speed engines were used for driving the existing propellers, it would be necessary to interpose gearing to reduce the rate of revolution. This is much objected to by many engineers, but it is possible that the advantages that would be gained thereby would outweigh its disadvantages.

It is only the reversal of the process that took place when the screw-propeller was first introduced. At that time there were no engines suitable to drive it direct, and the old type had to be utilized to drive it by means of multiple gearing. This, however, gave the screw the chance of proving its efficiency, and mechanical science soon produced engines capable of driving it direct. Improvements in the screw-propeller at present appear to have almost arrived at a standstill, so far as speed is concerned, but if gearing be admitted, the weight and space required for the engines could be materially decreased. In this case the gearing would be used to reduce the speed, and might be expected to work much more smoothly than when the reverse operation had to be performed. If the plan proved successful, we should have the satisfaction of knowing that if a high speed propeller were devised, the engines would be prepared and ready to drive it direct.

The engines of a first-class torpedo-boat, which weigh only 4¼ tons, develop 460 I.H.P., with a speed of 438 revolutions per minute. This is about the same power that is developed by the engines of the gunboats in Her Majesty's service. The engines of these boats, however, neglecting the boilers and propellers, weigh 27 tons, or more than six times the weight of the engines of the

torpedo-boat which develop the same power. In the torpedo-boats the cylinders are $12\frac{3}{4}$ inches and $20\frac{7}{8}$ inches diameter, with a 12-inch stroke ; the corresponding dimensions for the gunboat engines are—cylinders, 28 inches and 48 inches diameter, and stroke 18 inches. The speed of piston in the former case is 876 feet per minute, while in the latter it is only 378 feet. It is therefore clear that if the gunboat engines could, with safety, be replaced by those of the torpedo-boat type, and the propeller shafting driven by means of gearing, a considerable saving of weight and space might be effected.

How far this system would be generally applicable it is difficult, if not impossible, to predict. One thing is certain, viz. that in order to enable the weights to be much further reduced, the speed must be increased. The only way of obtaining this increase of speed of the engines, with the existing form and dimensions of propeller, is to drive the propeller shafting by means of gearing, so as to reduce the speed of revolution. Whether or not this is desirable, and likely to increase efficiency, can only be determined by experience. The point is, in my opinion, worthy of consideration, so that its relative advantages and disadvantages may be fully discussed and thoroughly threshed out.

In order to drive engines at high speeds of revolution it is desirable that the resultant driving forces on the crank should be made to be as nearly as possible uniform. To effect this, the *weights of the reciprocating parts* of the engines should be carefully adjusted to suit the required maximum speed, so as to cause the resulting tangential pressures on the crank-pin to vary as little as possible. It is very important that this should be carefully attended to in all high speed engines. The ordinates of the indicator diagram only give the pressures on the piston ; and to obtain the corresponding pressures on the crank-pin, it is necessary to combine, with the indicator diagram, a diagram showing the work expended on the acceleration and given out during the retardation of the motion of the reciprocating parts of the engines. It is therefore clear that *strength* is not the only point that should be considered in the design of these parts ; but that, if possible, their *weight* also should be so arranged that, when the engines are working at full speed, the effect of the inertia of the reciprocating parts may tend to produce uniformity in the tangential forces acting on the crank-pin. I am unable to do more than simply mention this point ; which, however, is one that may make all the difference between a smoothly and quietly working engine and one whose motion is irregular.

One other point requires to be mentioned with reference to the probable increase in the working pressures of steam, which, although it primarily affects the economy of steam, is also important as regards the strains on the framing and shafting, &c. The ordinary two-cylinder compound engine, with initial steam pressure of 80 to 90 lbs. per square inch, has now practically arrived at the same position, with respect to range of expansion and temperature in each cylinder, that the simple expansion engine, with steam of 30 to 40 lbs. pressure, was in when it was superseded by the compound engine. If, therefore, the pressures are increased beyond this limit, it will be necessary to divide the expansion of the steam into three stages in order to increase its practical effi-

ciency, and to reduce the maximum strains on the shafting, framing, &c. This has been carried out in a few ships, one of the most recent being the steamship Aberdeen, built by Messrs. R. & J. Napier, of Glasgow, and fitted with triple expansion engines, designed to be worked with steam at a pressure of 125 lbs. per square inch.

I cannot hope that I have done more, in this paper, than to have merely given a rapid and imperfect review of the changes that have taken place during the past fifty years in the relations between the size, speed, and power of marine engines, and to have indicated, so far as our present knowledge and experience serve as guides, what appears to be the most probable direction for future advance.

I think it will be admitted that the progress already made is great. To say nothing of the more special types of marine engines, which may perhaps be considered to some extent as experimental, we may just compare the Rhadamanthus, mentioned in the earlier part of this paper, the engines of which ship were built in 1832, with the Cleopatra, built in 1878. The machinery of the Rhadamanthus weighed 275 tons and developed 400 I.H.P. The machinery of the Cleopatra, which weighs 357 tons, developed at full power 2611 I.H.P. Machinery of the Cleopatra type, of the same weight as that of the Rhadamanthus, would be capable of developing 2011 I.H.P., or five times the power of the Rhadamanthus. It would appear from the recent trials of the Satellite that, with closed stokeholds under very moderate air pressure, machinery of modern design and construction would develop at least six times as much power as the earlier types of engines of equal weight.

One other feature is the great increase in the total engine power that can now be made available for the propulsion of ships. For example, take the case of the Terrible, which represented the finest type of steam war-ship of her day. Her maximum I.H.P. was less than 2000, and her speed about 10 knots. In the despatch vessel Iris, two sets of engines are fitted, capable of developing 7700 I.H.P., and of driving the ship at a speed of 18½ knots per hour. In several ships recently built, engines capable of developing 10,000 I.H.P. have been fitted.

So far as we are able to judge, the Terrible was as near finality in 1845 as the Iris and Inflexible are to-day. I think, therefore, we need not despair of the future, but may confidently look forward to still further progress in marine engineering. In what direction advance will be made it is, perhaps, unsafe to predict, but it does appear probable that the fields which afford the most enlarged scope for radical changes are the boilers and the propellers.

NAVAL MUSEUM OF HYGIENE.

NAVY DEPARTMENT, BUREAU OF MEDICINE AND SURGERY,
WASHINGTON, *August* 21, 1882.

Your attention is called to the appended prospectus of the Museum of Hygiene which has been organized under the Bureau of Medicine and Surgery, and officially recognized by Congress in an act making appropriations for its support for the fiscal year ending June 30, 1883, of which the following is a copy:

AN ACT making appropriations for sundry civil expenses of the government for the fiscal year ending June thirtieth, eighteen hundred and eighty-three, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the following sums be, and the same are hereby, appropriated for the objects hereinafter expressed for the fiscal year ending June thirtieth, eighteen hundred and eighty-three, namely:

For Naval Museum of Hygiene: For rent of quarters necessary for the preservation of objects already collected; transportation of contributions intended for exhibition; preparation of models and drawings to be used in the illustration of sanitary science and its progress, seven thousand five hundred dollars.

The necessity of a central institution of this sort has long been felt, and it is hoped that the present organization will supply this need. The plan briefly described comprehends a collection that shall be illustrative of the entire range of sanitary science, the establishment of a course of lectures by authoritative sanitarians from all sections of the country, and a library of sanitary science accessible, under proper restrictions and guarantees, to all who are engaged in the study of this branch of knowledge. This library already numbers many of the standard sanitary works in the English, French and German languages, and is constantly increasing. The following grouping of subjects and circulars will explain more minutely the scope of the enterprise.

PHILIP S. WALES,
Surgeon-General U. S. Navy.

CLASSIFICATION AND ARRANGEMENT.

A.—Department of Public Health and Comfort.

Class 1. Soil and atmospheric air.
" 2. Streets, roads, public places.
" 3. Removal of sewage, excrements and garbage.
" 4. Providing towns with water.
" 5. Public lighting.

Class 6. Providing cities with food.
" 7. Public laundries.
" 8. Public baths.
" 9. Public instruction.
" 10. The dwelling.
" 11. Buildings which are permanently occupied by many people.
" 12. Rooms which are temporarily occupied by many people.
" 13. Hotels, restaurants, coffee-houses, etc.
" 14. Factories, laboratories (chemical, powder, fireworks), metallurgic works, including dwellings for the workmen.
" 15. Agricultural works.
" 16. Heating and ventilating.
" 17. Food products.
" 18. Steam, horse and electric railroads.
" 19. Water transportation.
" 20. Clothing and treatment of the skin.
" 21. Preventing contagious diseases.
" 22. Hospitals, medical establishments, infirmaries.
" 23. Burial of the dead, vaults and morgues.
" 24. Veterinary department.
" 25. Fragments of exploded boilers, heaters, tubes, etc., damaged by pressure, frost, acids, scales and other deposits.

B.—Department of Life-Saving and Preserving.

Class 26. Life-saving from fire.
" 27. Protection against lightning.
" 28. Protection against inundations.
" 29. Protection against explosions.
" 30. Safety appliances in travelling on land.
" 31. Safety appliances in travelling on water.
" 32. Protection against accidents in submarine works.
" 33. Protection against accidents in mines.
" 34. Protection against accidents from machinery.
" 35. Attendance to persons accidentally injured in peaceful pursuits.
" 36. Attendance to persons wounded in war.
" 37. Ambulances, hospitals, barracks and hospital ships.
" 38. Apparatus for taking care of the wounded in war.
" 39. Marine architecture.

C.—Department of Literature and Drawings.

Class 40. Miscellaneous.
" 41. Literature and drawings appertaining to these departments.

NAVY DEPARTMENT, BUREAU OF MEDICINE AND SURGERY,

WASHINGTON, *January* 10, 1882.

The Surgeon-General of the Navy has established a Museum of Hygiene connected with this Bureau, which the American Public Health Association has made its permanent central repository.

It is intended that it shall exhibit the present state and future progress of the nation in all departments of hygiene, and to carry out this important scheme, the co-operation of physicians, engineers, architects, builders, manufacturers, inventors, and others interested in sanitary matters, is not only desirable but indispensable.

Contributions of articles, appliances, models, drawings, etc., illustrating improvements in food, water supply, bedding, clothing, marine architecture, house and hospital construction and furniture; apparatus for heating, illuminating, ventilation, and removal of excreta and refuse; culinary, laundry and bath facilities; appliances for physical culture and exercise; and whatever else tends to the preservation of health and the prevention of disease, are therefore solicited.

Contributions of materials and books should be sent to the address of the Surgeon-General of the Navy. Donors and depositors will, in every case, be duly credited on the descriptive labels of their exhibits.

Respectfully,

PHILIP S. WALES,
Surgeon-General U. S. Navy.

NAVY DEPARTMENT, BUREAU OF MEDICINE AND SURGERY,

WASHINGTON, *January* 15, 1882.

The Medical Officers of the Navy are informed that, in the application of a fund appropriated by Congress for sanitary investigations, the Surgeon-General has instituted a Museum of Hygiene connected with the Bureau, which is intended to exhibit the present state and future purposes of hygiene. In this undertaking the active interest and co-operation of the members of the Medical Corps of the Navy are expected, and it is desired that they will avail themselves of every opportunity to procure, both at home and abroad, contributions for exhibition of such articles as may have a bearing upon the preservation of health, the prevention of disease, and the comfort of the sick. There are many subjects which admit of a vast range of illustration, among which may be mentioned: models, drawings, and appliances suggesting improvement in house, hospital and marine architecture; apparatus for heating, ventilating and illuminating; discharge and disposal of excreta and refuse; food and water supply; clothing; appliances for exercise and physical culture, &c., &c.

Respectfully,

PHILIP S. WALES,
Surgeon-General U. S. Navy.

NAVY DEPARTMENT, BUREAU OF MEDICINE AND SURGERY,

WASHINGTON, *July* 12, 1882.

SIR: I would respectfully invite your attention to the importance of continuing the work at the U. S. Naval Laboratory and Museum of Hygiene that was started with an appropriation of $1500, made by the 46th Congress. It will be seen by the reports of the Bureau for 1879–'80, that much original research has been done in matters appertaining to the sanitary condition of the Navy, as regards ventilating, food-supplies, &c., and in the comparatively new and unworked field of atmospheric influences in the causation of disease. The results of these labors, published by the Bureau, have been eagerly sought by physicians and sanitarians throughout the country.

The models, apparatus, plans and diagrams illustrating naval and general sanitary subjects have been gradually accumulating, and they have been placed on permanent deposit at the Museum, and the Bureau is gratified to be able to state that officers of the Navy, physicians and sanitarians in various sections of the United States have made valuable contributions, and in a few years this collection will be unsurpassed in variety of illustration and in educative value, either in this country or abroad; and from its vast stores of instruction, officers of the Navy and sanitarians will be able to derive practical knowledge of the art of preserving health, not otherwise or elsewhere obtainable. The importance of this institution is shown by the fact that at the last meeting of the National Sanitary Association, at Savannah, Georgia, a resolution was unanimously adopted, making it the central depository of that widely influential and scientific society.

The Bureau would, therefore, knowing the deep interest you feel in the welfare of the Navy, invoke your influence and recommendation in securing a larger appropriation from Congress to continue the work thus successfully begun. I estimate that for the present fiscal year ten thousand dollars ($10,000) will enable the Bureau to accomplish the important object in view.

Very respectfully, your obedient servant,

PHILIP S. WALES,
Surgeon-General U. S. Navy.

HON. WILLIAM E. CHANDLER,
Secretary of the Navy.

The cost of the transportation of articles contributed will be paid by the Museum. When a contribution is received, the Museum will cause a descriptive label to be printed on which will appear the name of the giver. Thus labeled, the gift will be placed permanently on public exhibition.

J. M. BROWNE,
Medical Director U. S. N., in charge.

THE DRYING OF GUNPOWDER MAGAZINES.

By Prof. Charles E. Munroe, U. S. N. A.

In the Ordnance Instructions of the United States Navy, paragraph 1233, page 341, it is directed that, in order to absorb the moisture from a magazine, chloride of *lime* or charcoal should be suspended in an open box under the arch, and that it should be renewed from time to time.

On reading this I felt assured that an error had been committed, and that it had probably arisen from the fact that the chemical names of two quite different substances, chloride of *lime* and chloride of *calcium*, are really so very much alike in sense and sound as to be very often confused, and to be even regarded as synonymous by those who are not quite conversant with them.

Chloride of *lime* is the substance which is sold in commerce under the name of bleaching powder, and it is believed to generally consist of a mixture of CaO, CaH_2O_2, $CaCl_2$ and $Ca(ClO)_2$ or $(CaO)Cl_2$. When charged as completely as possible with Cl and when in its purest form it is regarded by Kolb* as having the composition represented by $Ca_3H_6O_6Cl_4$, which by the action of water is decomposed as follows:

$$Ca_3H_6O_6Cl_4 = CaH_2O_2 + CaCl_2 + Ca(ClO)_2 + 2H_2O.$$

When exposed to the air the bleaching powder absorbs water, probably in proportion to the $CaCl_2$ and CaO which it contains, but it is not regarded as a deliquescent salt. At the same time it absorbs CO_2 from the atmosphere, and the calcium hypochlorite is decomposed, probably in accordance with the reaction—

$$Ca(ClO)_2 + H_2O + CO_2 = CaCO_3 + 2HClO$$
$$\text{or } Ca(ClO)_2 + H_2O + CO_2 = CaCO_3 + H_2O + Cl_2 + O.$$

Chloride of *calcium*, on the other hand, has the formula $CaCl_2$. Its most distinguishing and characteristic property is that it is highly deliquescent; that is, it possesses the power of absorbing moisture from the atmosphere, when it is exposed to it, to such a degree as to become a liquid. So deliquescent is this substance that it is always used as the example of that property when it is defined. Brandes† found that 100 pts. of it, exposed to an atmosphere saturated with moisture for ninety-six days, absorbed 124 parts of water. The atmosphere has no further effect upon it than to liquefy it.

To compare the relative absorptive powers of these two substances, I exposed watch-glasses, containing, one ordinary bleaching powder, the other chloride of calcium, side by side under a bell glass in which a vessel of water had been placed. After an exposure of three days they were weighed, and it was found that while the bleaching powder had gained 30.70 per cent. in weight, the calcium chloride had increased 60.50 per cent. The data is as follows:

	Wt. taken. Grams.	Wt. found. Grams.	Increase. Grams.	Per cent.
Calcium chloride	22.2724	36.0195	13.7471	60.50
Bleaching powder	32.9250	43.0380	10.1130	30.70

*Ann. Ch. Phys. [4], **12**, 266.

† Schw. **51**, 433, and Watts Dict. Chem. **1**, 716.

The conditions of the experiment were quite favorable to absorption of moisture by the bleaching powder, for there was necessarily but a limited supply of CO_2 in the bell glass. When it is exposed to the air the CO_2 which it absorbs forms a crust of $CaCO_3$ over its surface, which impedes the absorption of moisture.

From the consideration, then, of the hygroscopic properties of these two substances it is evident that it is the chloride of *calcium* and not the chloride of *lime* which should be used as a desiccating agent for magazines, and as it is a by-product in the manufacture of chlorine and of chloride of *lime* or bleaching powder it ought to be obtained very cheaply. The porous chloride which has been dried at about 200° C. is better adapted for absorbing water than the fused chloride, since the latter contains both CaO and $CaCO_3$ as a result of igniting the chloride in contact with air.

In addition to the fact that bleaching powder is not the most efficient desiccating agent, either as regards its power or its price, it has occurred to me that, owing to certain other properties which it possesses, it might prove to be a very objectionable substance for use for this purpose.

It is known that after gunpowder has been stored for some time its initial velocity is reduced. This is held to be due to the absorption of moisture and the consequent efflorescence of the nitre. While recognizing the force of this explanation, I have surmised that there are other causes for this deterioration, and that one of them might be found in the slow oxidation of the sulphur, its conversion into sulphuric acid, the decomposition of the nitre with the formation of potassium sulphate and nitric acid, and then the further oxidation of sulphur by this nitric acid. The potassium sulphate thus formed would act, like the glass in Gale's process, or the graphite, charcoal, and so on, of Piobert and Fadéieff, for gunpowder; the silica in use for the silicated gun-cotton, or the camphor in the gum dynamite, to reduce the rate of inflammation, or of the transmission of the explosive undulations. The most satisfactory way for testing this theory would be by examining samples of fresh gunpowder for sulphuric acid, and then, after it had been exposed for some years to the incidents of storage and transportation which obtain in the service, to examine the same lot of powder again. I have not as yet had an opportunity for putting the theory to the test.

It, however, seemed probable to me that if oxidation, of the nature spoken of, could take place in the presence of air and moisture only, it would certainly be hastened by the presence of bleaching powder, since when the latter is exposed to the air the CO_2 absorbed decomposes it in accordance with the reactions given above by which chlorine or oxides of chlorine are liberated. These products in the presence of water are powerful oxidizing agents and will consequently act more energetically than the oxygen of the air alone. To test this I arranged an apparatus so that washed CO_2 might pass into a bottle in which bleaching powder suspended in water was placed, and the washed product of this reaction was passed into a flask in which the gunpowder to be tested was suspended in water. The gunpowder taken for the test was Oriental.

Two portions of this powder were weighed, each being placed in a separate flask, and 200 cm. of distilled water added to it. Through one of these the gas from the bleaching powder was allowed to bubble for twelve hours and then it remained standing for some time. It was exposed to the action of the gas in all for 36 hours, most of the time being in strong daylight. The other flask stood, uncorked, for the same time in another room. Both were now filtered and 100 cm. of each were taken and treated with hydrochloric acid and barium chloride. The precipitate obtained in each case was washed and ignited as for the determination of sulphuric acid. The results were as follows :

	Wt. taken, grms.	Wt. $BaSO_4$ fd. grms.	Per cent. S oxidized.
Samples exposed to air, ...	3.4070	.0266	0.16
" " " bleaching powder,	4.0692	.4768	1.60

That is, that in the sample of gunpowder exposed to the bleaching powder, there were ten times as much sulphur oxidized as in that which was exposed to the air.

The method of experiment described above was employed because it was known that the state of solution would favor the change, and it was supposed that, under the conditions which prevail in magazines, a marked change would not be noticed except after a considerable length of time. However, an experiment was set on foot which imitated the conditions exactly. I put a quantity of bleaching powder in the bottom of a desiccator, and on the shelf above I put a weighed quantity of the Oriental superfine saltpetre powder, in the granulated, glazed state in which it is sold. The desiccator was then covered and set aside. At the end of twenty-six days I examined the powder, and was surprised to see an appearance of change on the surface of the powder granules ; so I immediately dissolved in hot water, filtered and precipitated with barium chloride and hydrochloric acid. For comparison, I made another determination of the sulphates in the fresh powder. The results are as follows:

	Wt. taken. grams.	Wt. $BaSO_4$ fd. gram.	Per cent. of S oxidized.
Fresh powder, ...	6.6818	.0816	0.17
Powder exposed 26 days to atmosphere of bleaching powder, . . .	6.0256	.6566	1.50

It would seem to follow, from the above results, that while the chloride of *lime* is not so efficient a desiccating agent as the chloride of *calcium*, it is at the same time very objectionable, since it *may* cause a serious deterioration of the gunpowder.

I propose hereafter to examine samples of powder which have been acted upon by the gases from bleaching powder, by means of a method which I have recently devised for testing the incorporation of gunpowder, and I hope, before long, to have the honor of describing this method to you.

RESPONSIBILITY.

From the pamphlet of an unknown author, supposed to be the Archduke Albrecht of Austria.

The sense of responsibility will crush a faint-hearted man, but will stir up to enthusiasm and energy a man of power, will make him form a true judgment of what is wanting in him to perform the task set him, and cause him to acquire that which he finds wanting. He must have perfect control over himself, and be ready to undergo all self-denial.

1. If a General-in-Chief is not supplied with the necessary means, or if his influence over his subordinates is hampered, then *his* responsibility ceases, and those who hamper him are solely responsible for all that happens.

2. If *full powers* are given to a General, *his* is the responsibility, and that of other authorities vanishes. It is highly important that the above facts should be generally known and appreciated.

The most serious responsibilities will rest on the statesman who does not keep the General Commanding fully informed of the political situation in all its aspects, for the action of the latter cannot be otherwise than paralyzed if he is not so kept informed.

The General is personally responsible for all orders which emanate from his headquarters.

All his Staff are bound to second him with the utmost devotion, and each must bear the responsibility of the execution of that which is confided to him ; for, as an efficient staff can never supply the want or make good the failings of an incompetent commander, so a commander, however able and energetic he may be, can never overcome the fatal consequences which must accrue from the inability or negligence of his subordinate commanders or staff, nor can he occupy himself with carrying out the details of execution which it is their, and only their, province to perform.

Subordinate commanders must be allowed much independence ; for they are not only responsible for the carrying out of the orders they receive, but they must act also up to the spirit of them, and interpret them according to the situation of the moment. Hence the importance of issuing good and judicious orders, and hence may be seen the difficulty of so doing, the responsibility of which rests wholly and solely on the chief.

The larger the force, and the greater the ground covered, the greater the difficulty in giving orders ; the eye can no longer guide, and information takes its place. Thence it is more than ever impossible for the General to give orders as to details, or to furnish copious explanations as to carrying them out. The end to be attained, and the "general idea" for doing so, must be communicated, but details must be left in the hands of subordinate commanders. All ranks down to the sub-officers should be made acquainted with the end in view, and a certain amount of independence and initiative should be accorded to each, and thus a healthy chain of responsibility will be established and the

moral *status* of all ranks elevated. Needless to say that such can only be done where the army has received a complete and careful training, and where it is animated by a good and patriotic spirit.

To sum up:—The orders of the chief must be explicit, and show forth the object, and his idea as to how it is to be attained. Details must not be entered into. The responsibility of the subordinate commanders falls on all commanders subordinate to them, though in a lesser degree, according as the scale descends.

The commander of a regiment is responsible for the state of his men; the General should exercise a general supervision, point out faults, and report as to his fitness for his position; but nothing can be worse than interference in details; for it undermines the respect due to the Colonel from his own subordinates. This rule should be observed down the scale, as the officers commanding the component parts need also a share of independence and initiative to secure respect and inure them to accepting responsibility.

The fault of endeavoring to secure centralization is only too common; its disastrous consequences unfortunately only become apparent in time of need, when it is too late to repair the deadly results caused by it. No too strenuous efforts can be exerted, while there is yet time, to root out this destructive vice, for when the time for action comes it will be too late.

Experience shows that a man whose mind is overloaded with details will fail when the important moment comes, for his mind is so full that he cannot grasp more.

A healthy chain of responsibility from the highest to the lowest raises the value and confidence of all, and gives calm and assurance even in the most critical moments; nothing begets the valuable "*sang froid*" which alone helps at such a time, but the knowledge that one possesses responsibility, and *is inured to it.*

Small minds will endeavor to reject responsibility, great minds will eagerly grasp it.

In giving orders, brevity, clearness, precision, should be insisted on; the object in view should be clearly given out: long orders, copious details must be avoided, and above all, the bureaucratic passion for holding all the threads and issuing the minutest instructions must be rigorously stamped out.

The following rules are given as most important and conducive to the object of properly apportioning responsibility through various grades:

1. The sphere of action of every one must be strictly and precisely defined.

2. No superior must be allowed to interfere in the sphere of action of a subordinate.

3. The fewest number of officials consistent with the due performance of duties should be employed.

4. Greatest care should be taken to prevent work becoming merely mechanical; this can only be done by avoiding multifarious returns and other such work. What work is done should be of utility.

5. Over-anxious and indolent subordinates love to refer matters; when they refer matters which it is their duty to settle themselves, their references should be returned with a "wigging," and without any other answer.

6. When centralization rules, and when responsibility is not distributed, the removal of the chief, who directs everything, must produce disaster—the head goes, and the limbs, which merely act mechanically in obedience to it, become paralyzed and useless. Centralization and properly distributed responsibility cannot be co-existent, and the former must be stamped out with an iron heel before we can hope to establish the latter.

BIBLIOGRAPHIC NOTICES.

ANNALEN DER HYDROGRAPHIE UND MARITIMEN METEOROLOGIE.

PART I, 1883. The physical geography and meteorology of the Cape of Good Hope. The deep sea soundings of the Siemens steamer Faraday. Hurricane in the Indian Ocean in May, 1881. Rules for the handling of chronometers. Entries at the German signal stations for September, 1882. Thursday Island. Comparison of the weather of North America and Central Europe for October, 1882. Log notes and tables.

PART II. The physical geography and meteorology of the Cape of Good Hope. A solution of the method of double altitudes. Comparison of the weather for November, 1882. Entries at the German signal stations for October, 1882. Log notes and tables.

PART III. Results of five years' meteorological observations at Wilhelmshaven. The deep sea soundings of the Faraday. Solution of the method of double altitudes. Recent deep sea researches of the Triton in the North Atlantic. Entries at the signal stations for November, 1882. Comparison of the weather for December, 1882. Log notes and tables.

ENGINEER.

MARCH 9. Electrical Transmission of Power, by Prof. Oliver J. Lodge. A Torpedo Boat Collision.

During some manœuvres around one of the large Italian ironclads in the Gulf of Spezzia, two torpedo boats, built by Yarrow & Co., came into collision. The two boats were running at a speed of nearly 14 knots, which was perhaps reduced to 10 knots at the instant of collision. The Falco was saved from sinking ,partly by the water-tight bulkhead, which happened to be close to where she was struck, and partly by her pumping machinery. The fore end of the ram of the other boat not only penetrated the starboard side, but went right through and out beyond the port side of the Falco. However both boats could steam on, and reached the dockyard at Spezzia in safety. The engines and all the accessories on board the Falco sustained no damage by the shock, which was confined entirely to the head of the boat; and had the boats been less substantially built, one at least must have gone to the bottom. One important feature in these boats is an arrangement introduced by Messrs. Yarrow & Co., by which means, if the fire room became flooded, the fires would not be extinguished, which, on account of the low position of the fire grate in vessels of this class, would otherwise almost instantly result from only a small quantity of water finding its way into the fire room.

Taylor's Initial Stability Indicator for Ships.

The object of this indicator is to measure and show by simple inspection the metacentric height under every condition of loading, and therefore to make known the stability of the vessel.

MARCH 16. On Certain Points of Importance in the Construction of Ships of War.

A paper read before the Institute of Naval Architects by Captain G. H. Noel, R. N., in which the author confined himself principally to the following points: (1) The strength and height of the bow necessary for ramming; (2) On water-tight compartments; (3) On armored conning towers; (4) On torpedo defence.

Bulkheads. By Mr. James Dunn.

An important and suggestive paper dealing with vessels of the mercantile marine, in which the author submits three propositions for consideration: (1) Is the subdivision of a merchant ship by water-tight bulkheads practicable, and consistent with commercial requirements? (2) Can these bulkheads be made sufficiently strong to withstand the pressure of water under all circumstances? (3) Are bulkheads of any value in securing floating power in the event of damage from collision?

The Efficiency of Guide Blade Propellers, by Mr. Thorneycroft. Brewtnall's Suspension for Electroliers.

The object of this invention is to enable the principle of the ball and socket joint to be applied to the suspension of electroliers and to the mounting of other swinging or movable fittings for the electric light, by providing through the medium of this joint for the maintenance, unbroken, of the electrical circuit when the electrolier or other fitting is swung or rotated.

MARCH 23. A Description of a Method of Investigation of Screw Propeller Efficiency.

A paper by Mr. R. E. Froude describing a particular method of investigation of screw propeller efficiency by means of experiments on models. The distinguishing characteristic of this method is the division of the subject into two principal branches, viz. The efficiency of screws working by themselves in undisturbed water, and the manner in which the efficiency is affected by the screw being brought into conjunction with the hull of a ship.

MARCH 30. Hogging and Sagging Strains in a Seaway, read before the Institute of Naval Architects, by Mr. W. E. Smith. Radial Valve Gear. The Construction and a Discussion of the Elements of the Crewe Gear, by Robt. Hudson Graham, C. E.

APRIL 6. A Method of Reducing the Rolling of Ships at Sea, by Mr. P. Watts.

The object of this paper was to draw attention to a method of reducing the rolling of ships at sea by means of the device known as "water chambers." These were compartments across the ship into which free water might be admitted when it was required to reduce rolling. This method was adopted in the Inflexible, and the chief advantage is derived from the change effected in the righting force. The way in which it operates in this respect can be understood by regarding the water as doing the reverse to what is done by men in the process of rolling a ship in still water. The men are timed to run in advance of the roll, and their weight tends to increase the heel; whereas the water in the chamber necessarily lags behind the roll, as the chamber must become inclined before the water has any tendency to run across by its own weight; and therefore tends to diminish the heel. Thus the effect of the water chamber is to increase the righting force which opposes the motion as the ship heels over, and on the return roll to lessen the righting force, and cause the ship to move more slowly, so that she acquires less angular momen-

tum on reaching the upright position, thus tending to make her roll less deeply the other way.

The complete experiments on this apparatus were interrupted on account of the Inflexible being required for service at Alexandria, but further experiments are shortly to be made which will settle some questions which yet remain to be decided.

APRIL 13. Automatic Water Wheel Governors, by Mr. J. H. King. The Transmission of Power by Electricity, by Mr. Alexander Siemens.

APRIL 20. A New Gas Engine, by Mr. E. J. Frost, Philadelphia. Some Points in Electric Lighting: a Lecture before the Institution of Civil Engineers, by Dr. John Hopkinson, F. R. S.

ENGINEERING.

MARCH 2. Modern Machine Tools. Locomotive Valve Gear, designed by G. H. Strong, Philadelphia.

This valve gear possesses a number of novel features, and is a decided departure in almost every respect from the gear in common use. The valve motion is a modification of the Joy valve gear, but arranged to work steam and exhaust valves independently, in order to obtain any desired point of cut-off without affecting the exhaust. Incidentally, this dividing the valve practically into four pieces enables clearance to be cut down to about five per cent.

MARCH 9. Hopkinson's Current Meter.

An apparatus for measuring the electric supply to a house or factory, based on the principle of energy or work meters.

Blast Furnace Gases as a Source of Ammonia.

A discussion of the question of recovering ammonia from blast furnace gases and other new sources, such as Siemens and Wilson's gas producers.

MARCH 16. Steam Trials under Forced Draught.

A paper read before the Institute of Naval Architects by Mr. R. J. Butler, on the steam trials of the Satellite and Conqueror under forced draught. The fire room was of the enclosed type, and the air pressure used varied from 1 to 1½ inches of water. With similar boilers under the most favorable conditions from 10 to 10½ horse power is obtainable per square foot of grate, without forcing the draught; and nearly 13 horse power or about 24 per cent. more can be realized when the ordinary steam blast is used, the fire room being open as usual. With the enclosed fire room and forced draught, however, the highest result reached was 16.9 horse power per square foot of grate, as a mean of two hours' trial.

This exceeds the performance under natural draught by about 62½ per cent., and that under steam blast by 30 per cent. These trials were made with the object of observing the behavior of the boilers, and of realizing the maximum power obtainable, so the duration of the trials was necessarily short, too short in fact to admit of any account being taken of the rate of combustion of the fuel, so no estimate can be given of the quantity of coal burnt under this system of forcing the draught; but neither in the generation of steam nor in its employment in the engine is economy to be expected by this method of working the boilers. Neither is economy necessary for the few and comparatively short periods that the boiler will be required to be forced in this manner.

Board of Trade Rules for Boilers. Fog Signalling.

MARCH 30. Torpedo Attack and Defence. Ball's Unipolar Dynamo Machine.

APRIL 6. The Armament of the New Italian Field Artillery. The Strength of Corrugated Flues.

A report on the strength of Fox's corrugated flues, made by Mr. Wm. Parker, Chief Engineer Surveyor to Lloyd's Register.

Strains on Steamers.

A paper read before the Institute of Naval Architects by Mr. W. Richardson, on the Modes of Estimating the Strains to which Steamers are Subject.

Knowles' Automatic Supplementary Governor.

The action of a centrifugal governor produces only an approximate uniformity of speed in a steam engine. Many attempts have been made to produce governors that should not be subject to this disadvantage, and the apparatus under consideration presents a simple and effective method of overcoming the difficulty. Instead of seeking to produce a theoretically perfect governor, Mr. Knowles has adopted the existing type, and has corrected its variations by the aid of a supplementary apparatus, which consists of a small centrifugal governor, having upon its spindle two friction disks, situated so far apart that there is room for a friction bowl to be placed between them. When the engine runs at its normal speed both friction disks are clear of the edges of the bowl, but the slightest alteration in speed brings one plate in gear with the disk, and thereby rotates it. This motion may be utilized in various ways in controlling the engine. The main work of controlling the engine depends upon the large governor, while the variations due to the different positions of the governor balls are compensated by the small governor.

Arnold's Electric Alarm Gauges.

An attachment for pressure gauges designed to act as an additional safeguard when used on boilers or vessels subjected to a pressure. The attachment is applicable to diaphragm or other form of gauges, and can be applied to gauges now in use without altering or impairing their adjustment.

APRIL 13. Boiler Explosions in 1882: annual report of E. B. Marten, Chief Engineer to the Midland Boiler Inspection Company.

APRIL 20. Hitting Objects at Sea. The Strength of Shafting.

A valuable paper on the strength of shafting when exposed both to torsion and end thrust, by Prof. A. G. Greenhill.

The Raising of the S. S. Austral.

This vessel, which sank in 50 feet of water in Sydney harbor, has now been raised. The weight lifted was approximately 6000 tons, and the means adopted consisted in securing to the ship's sides artificial water-tight bulkheads reaching to several feet above the water line, then transferring her from a submerged to a stranded vessel full of water, but having the gunwale above the water line. To render it possible to turn the vessel lengthwise, she was divided into two equal compartments by a transverse bulkhead amidships, the doors in the other bulkheads being left open. The vessel thus prepared was pumped out by powerful pumps, placed equally before and abaft the transverse bulkhead. The vessel first came upright, and then steadily left the bottom, and as the pumping proceeded was towed into shallower water.

INSTITUTION OF MECHANICAL ENGINEERS. England.

JANUARY. Condition of Carbon in Steel.

Prof. F. A. Abel presented a report on experiments made to determine this

point. By treating steel with potassium bichromate and sulphuric acid the iron was dissolved out, with a grey-black strongly magnetic residue. This was found to be apparently a chemical compound of carbon and iron, approximating to the formula Fe_3C or to some multiple thereof. The average amount of the carbide when using dilute solutions was 14 parts in 100 of steel, and the carbide contained about seven per cent. of carbon.

Prof. Abel sums up as follows: "The results of these experiments with cold-rolled steel of a *particular composition* appear at any rate to confirm the correctness of the view that the carbon in cold-rolled steel exists, not as simply diffused mechanically through the mass of the steel, but in the form of an iron carbide—a definite product, capable of resisting the oxidizing effect of an agent which exerts a rapid solvent action upon the iron through which this carbide is distributed. Whether this carbide varies in composition to any great extent in different descriptions of steel, which are in one and the same condition of preparation (*i. e.* cold-rolled or annealed), remains to be demonstrated by further investigations, if the determination of this point is considered of sufficient importance to warrant the expenditure of the time and labor which it would involve. The preliminary experiments with small specimens of cold-rolled, annealed, or hardened steel, described last year, appeared to warrant the belief that the condition of the carbide in the metal is affected to such an extent by the process of hardening, as more or less completely to counteract its power to resist the decomposing effect of such an oxidizing agent as chromic acid solution. How far this may always be the case, and how far it may be possible to prove that similar effects to a modified extent are produced by the submission of steel to tempering processes in different degrees, may perhaps be determined by further research in this direction."

Molecular Rigidity of Tempered Steel.

Prof. D. E. Hughes reported results obtained on different metals with a modified form of the induction balance. Two hundred metres of small copper wire were coiled on a hollow bobbin, through the centre of which passed the wire or rod to be experimented upon. The coil was movable so that it could be placed over any portion of the length of the wire, or rotated that its axis might form any desired angle. One end of the wire was arranged so that any desired degree of torsion could be given to it, and the torsion be indicated by a pointer. A telephone was placed in the coil circuit, and a current passed through the wire. If the plane of the coil was 90° from the direction of the wire, nothing was heard in the telephone, but currents were induced by the slightest rotation of the coil. If, however, a piece of iron were laid near the wire, not parallel either to it or to the plane of the coil, a current was induced in the latter. If now an iron wire was passed through the axis of the coil and intermittent currents were sent through it, there was no induction in the coil, but when the iron wire was twisted strong currents were perceived. By reversing the direction of the twist the direction of the induced currents was also reversed. By increasing the twist in one direction there was no increase in the induced current; and on reversing the twist, although the original condition of torsion had not been regained, there was an immediate reversal of the current. While the wire is twisted the approach of a magnet will stop the induced currents. From this Prof. Hughes infers that the phenomena are produced not by the torsion given to the mass, but to the molecular rotation produced by the torsion.

The most remarkable feature of the experiments is that none of these results can be obtained with tempered steel. No amount of torsion induces currents. Conversely, if while a current is passed through the wire, it is heated red hot, currents are induced, showing that under the magnetic influence of the current the molecules have rotated. When cooled again this position is retained, and the steel now gives induced currents which cannot be prevented by any

amount of torsion. An iron bar similarly treated gives induced currents when hot, which disappear on cooling.

The experiments are detailed at length, and the conclusion of Prof. Hughes that in tempered steel the molecules are almost rigid, seems irresistible.

JOURNAL DE LA FLOTTE.

MARCH 18. The Belleville Boiler in Use aboard the Voltigeur.

This boiler, described in No. 23 of the Proceedings, has been used aboard the Voltigeur for over two years, and a report of the commanding officer is given specifying the condition of the different working parts at the end of that time.

"The vessel went into commission towards the end of 1879, and in January, 1880, they made the first trials, of which we have published the results. To-day we complete this information in giving a recapitulation of the official report, which contains observations made, after a careful examination of the motive machinery, of a nature as interesting to the merchant marine as the navy.

It says the engine proper has been constructed at the Indret works. It has three horizontal cylinders of the Wolf system, high pressure, with variable cut-off, surface condenser, besides it is a back-acting single screw engine. Since the ship started out in September, 1880, the engines have always worked with regularity.

In several examinations of the cylinders the surfaces were found covered with a light layer of soft grease, which seems to indicate that the employment of the mineral oil, "valvoline," as a lubricant, gives good resultants. The quantity of oil introduced in the cylinders is 300 grammes per hour, while running full speed under way at, say, 80 revolutions, 250 grammes at moderate speeds, 60 to 70 revolutions, and 200 grammes running slowly below 60 revolutions.

The examination of the condenser has not shown anything unusual. The tubes remained clean, having a very slight coating of grease. This result appeared to be owing to the introduction of carbonate of lime. The vacuum varied between 65 and 70 centimeters, varying with the speed of the engine.

At the beginning of the cruise the chambers of the clap valves of the feed pumps were obstructed by a mixture of grease and lime, but it was remembered that during the trial trips the cylinders had been lubricated with ordinary oil; the use of mineral oil after this, without previously washing out with lye, resulted in decomposing this grease, and formed a solid residue in quantity sufficient to stop the feed water, and necessitated an immediate examination. After a very careful cleaning this did not reoccur, and the feed valves have always been found in a satisfactory state.

Later the employment of a carbonate of lime, which precipitates on the bottom of the ejectors the mineral oil introduced in the boilers, and which neutralizes the small quantities of hydrochloric acid resulting from the decomposition by heat of the chloride of magnesium contained in the sea water, has caused the entire absence of all danger of choking the feed pumps or the holes of the feed water strainer; besides, they appeared sensibly cleaner.

The steam purifier of the Belleville system is in good condition; it is one of the most important parts of the engine. It serves to deprive the steam of water and foreign substances which would otherwise be carried over to the cylinders, as they have been able to ascertain by the muddy deposits and accumulated grease in the lower part of the purifier; this apparatus fulfils its purpose perfectly.

In conclusion, the machinery of the Voltigeur is in excellent condition, and serviceable for a long time to come.

The evaporating apparatus of this vessel is of the Belleville system, designed in 1877 for high pressure. It is composed of six generators of 100 horse power each, united under the same sheet-iron shell and placed back to back, so as to form two fire rooms fore and aft. . . .

The tubes which contain the generating elements and their connections have not suffered any deterioration. At each examination of the tubes they found in those which belonged to the lower rows a layer of scale varying from 1 to 1½ mm. in thickness; it is hardly appreciable in the tubes of the upper part of the generator. Before they made use of the carbonate of lime these last were covered with a layer of grease due to the "valvoline" oil; but following the new treatment, this deposit has almost entirely disappeared, being replaced by a dry dust, fine and grayish-colored, slightly adhering, showing plainly the carbonate of line was absorbed by the mineral oil in such a manner as to make it heavy enough to deposit at the bottom of the purifiers, from whence it is removed by the blow-offs.

The tubes have been completely cleaned three times during the cruise, it being necessary to perform this operation at least every six months to keep the elements constantly clean.

To this end it is economical of time and labor to make use of compressed asbestos gaskets for the joints of the plugs, which are removed for cleaning the tubes of the generators.

Red lead joints require a very long time to be opened, scraped, and replaced with a new mastic (putty). The compressed asbestos gaskets give, on the contrary, perfectly tight joints, quickly made and of small cost.

The steam purifier and feed collector have always performed their duty well, which is to precipitate instantly to the state of powder the calcareous scale by the rapid reheating of the feed water in contact with the steam during its passage in these receivers, and of separating the water and the foreign matter with the vapor.

In the examinations they found in the purifiers a layer of greasy matter and iron rust from 3 to 4 mm. thick, which is thicker near the induction end. The ejectors have never been filled to the height of the eduction pipe.

The system of forced draught, which is composed of fine jets of steam in the chimney, has been employed only for the purpose of cleaning and sweeping the chimney, and occasionally to increase the combustion of bad coal taken on board during the cruise.

It can be said that the boilers of the "Voltigeur" are at this moment to be found in as good condition as at the beginning of the cruise. They will be able to be preserved for a long time yet, if care is taken to have them filled with fresh water as soon as they are put out of service; and if fresh water is not obtainable, salt water can be used with lime added.

MARCH 15. Small Pictet Ice Machine for Use aboard Ships.

Said to make from eight to ten pounds of ice per hour, with the expenditure of one horse power. The principle is the same as that of the larger machines made by M. Pictet for the condensation of gases, that of the volatilization and subsequent condensation of sulphurous anhydride. As the whole cycle of operations is performed in one machine, there is theoretically no loss of material and the apparatus is always ready for use, but arrangements are made for renewing the supply of the liquid anhydride as it is lost in practice. The machine can be worked by hand at a slower rate if power is not available.

APRIL 22. Floating Lighthouses for the Atlantic.

A scheme to establish one or more lighthouses 42 m. high, floated on large platforms, which, being water ballasted, would have sufficient stability to keep the towers vertical. The idea is thought to be almost chimerical, but attention is called to the fact that floating meteorological stations moored in mid-ocean and in telegraphic communication with the shore would be of commercial importance, in giving warning of the approach of hurricanes to vessels in their vicinity as well as to the shore stations. Considering that some of the severest gales of Western Europe reach the land without having given notice of their approach, and that the English meteorological service is frequently unable to

make any predictions of storms from the west, it would seem as though the expense of maintaining a meteorological station in mid-Atlantic would be much less than the loss now experienced by shipping in storms of whose approach no warning can be given.

MILITARY SERVICE INSTITUTION OF THE UNITED STATES.

No. XIII. Improvements in the Art of War in the Last Twenty Years, by Captain F. V. Green, U. S. Engineers. (First Honorable Mention Prize Essay.)

MITTHEILUNGEN A. D. GEBIETE DES SEEWESENS.

VOL. X, PART 12, 1882. Upon the quality of cast steel for use in shipbuilding. The trials of armor plates at Spezzia. Firing trials at Krupp's works. Trial of the new breech-loading 100-ton Armstrong gun at Spezzia. Table for the correction of the heeling error. The Greek torpedo boat Psara. The reform in the lower Naval School. The extent of the coast formation. Cannon of small calibres.

VOL. XI, PART 1, 1883. Discussion of the different methods for the solution of the problem of the orthodromic course. The rig of ship's boats in the English, French, Russian and German navies. The observations on the transit of Venus of December 6, 1882. Notes on the English, French, Italian, American and Brazilian navies. Launching of the Swedish gunboat Edda. Torpedo boat for the Dutch navy. The Russian program for naval constructions in 1883. 15 cm. bronze and steel tubes in Spain. Thomasset's machine for testing material. New theory of the formation of hail.

PART II. A study of the construction of ships and ship's machinery. Rules for the care and handling of chronometers, Negus. The budget of the French Navy. The budget and the rules for the advancement of officers in the United States Navy. Comparative test of 12-inch compound and Schneider plates at Achtenfelde, near St. Petersburg. Comparative test of armor plates at Muggiano. The submarine torpedo battery. Notes on the English Navy. Lundborg's steamship model. Shipbuilding in Austro-Hungary in 1882. Examination of the officers of the Austro-Hungarian merchant marine. The history of navigation. The history of the Austro-Hungarian Lloyd. Star map of the northern heavens of Schneider and Weinek. New vessel for the Russian fleet in the Black Sea.

REVISTA GENERAL DE MARINA.

MARCH. Notes on naval service in the Philippines. The London electrical exhibition. Interior organization of men-of-war. Notes on the Manilla hurricane of October 20, 1882. Notes on combined military and naval operations.

RIVISTA MARITTIMA.

FEBRUARY. The battle of Zouchio (1499). Naval manœuvres in war. Experiments at Spezzia on 48m. plates. The naval appropriations. The problem of the mercantile marine in England and the United States.

MARCH. Naval appropriations. Transverse bulkheads in iron ships. Notes on naval hygiene. The operations of the French navy in Tunis. Gibraltar and the Key of the Straits. Experiments against armor at Spezzia. Effect of oil on waves. The systems of naval administration in different countries. Notes on naval matters.

APRIL. The state of the Italian mercantile marine. The naval appropriations. Hydraulic safety-brake of elevators for furnishing ammunition to the 100-ton guns. The relations between size, velocity and power in steam engines. Military ports, Toulon. The trial of the Polyphemus.

BOOKS RECEIVED.

Annalen der Hydrographie und Maritimen Meteorologie. No. 12, 1882. Nos. 1, 2, 3, 1883.
American Geographical Society. No. 4, 1882. Nos. 1 & 2, 1883.
American Society of Civil Engineers. Jan.–Mar., 1883.
American Society Mechanical Engineers. Papers.
Giornale d'Artiglieria é Genio, 1883. Official, Nos. 1 & 2. Unofficial, January.
Harvard University Bulletin. April, 1883.
Journal de la Flotte. Nos. 10–16, 1883, inclusive.
Journal of the Franklin Institute. April–May.
Journal of the Military Service Institution of the United States. No. 13.
Mittheilungen a. d. Gebiete des Seewesens. Nos. XII, 1882, I & II, 1883.
Ordnance Notes U. S. Army. Nos. 233–254.
Reunion des Officiers, Bulletin. Nos. 5–17, 1883, inclusive.
Rivista Marittima. March & April, 1883.
Report of Experiments at Spezzia.
School of Mines Quarterly. No. 3, Vol. IV.
Société des Ingénieurs Civils. Mémoires, Dec. 1882 & Jan. 1883.
Weights and Measures. (From Proceedings Amer. Soc. Civil Engineers.)

Report of the Director-General. Vols. 1–2. Centennial International Exhibition, 1876.
Reports of the Officers of the Centennial Commission. Appendix to the Reports.
Presented by Rear-Admiral Thornton A. Jenkins, U. S. N.

Plans of the New Ironsides. (These plans are the only ones in existence.) Presented by Lieut. E. W. Very, U. S. N.

NAVAL INSTITUTE PRIZE ESSAY, 1884.

A Prize of one hundred dollars and a gold medal is offered by the Naval Institute for the best Essay presented, subject to the following rules:

1. Competition for the Prize is open to all members, Regular, Life, Honorary and Associate, and to all persons entitled to become members, provided such membership be completed before the submission of the Essay. Members whose dues are two years in arrears are not eligible to compete for the Prize until their dues are paid.

2. Each competitor to send his essay in a sealed envelope to the Secretary on or before January 1, 1884. The name of the writer shall not be given in this envelope, but instead thereof a motto. Accompanying the essay a separate sealed envelope will be sent to the Secretary, with the motto on the outside and writer's name and motto inside. This envelope is not to be opened until after the decision of the Judges.

3. The Judges to be three gentlemen of eminent professional attainments (to be selected by the Executive Committee), who will be requested to designate the essay, if any, worthy of the Prize, and, also, those deserving honorable mention, in the order of their merit.

4. The successful essay to be published in the Proceedings of the Institute, and the essays of other competitors, receiving honorable mention, to be published also, at the discretion of the Executive Committee.

5. Any essay not having received honorable mention, to be published only with the consent of the author.

6. The subject for the Prize Essay is, "*The best method for the reconstruction and increase of the Navy.*"

7. The Essay is limited to forty-eight printed pages of the "Proceedings of the Institute."

8. The successful competitor will be made a Life Member of the Institute.

9. In the event of the Prize being awarded to the winner of a previous year, a gold clasp, suitably engraved, will be given in lieu of a gold medal.

CHAS. M. THOMAS,
Secretary.

ANNAPOLIS, MD., *May* 3, 1883.

THE DEVELOPMENT OF ARMOR FOR NAVAL USE, BY LIEUTENANT EDWARD W. VERY, U. S. N.

The next issue of the Proceedings of the Naval Institute (Vol. IX, No. 3—Whole No. 25) will be entirely devoted to an article by Lieutenant Edward W. Very, on the Development of Armor for Naval Use. The number will thus be a complete work of itself, fully illustrated, and will possess more than ordinary interest, in being the only work extant devoted exclusively to the details of armor development. The subject is treated under six separate heads or chapters, as follows:

I.—*Projectile Energy and Armor Resistance.*

Under this caption, the action of projectiles on armor is discussed. The absolute measure of the magnitude of muzzle energies is given, and the sources and amounts of wasted energy, useful energy, and surplus energy are described and fixed. The Punching and Racking theories are discussed, together with the effect that armor development has produced upon the bases of these theories.

II.—*Iron Armor and Smoothbore Guns in Europe.*

The condition of naval artillery at the time of the introduction of armor. The first projects for armoring ships and the first armor experiments. The French and English floating batteries. The action with the Kinburn forts. First improvement in armor manufacture. Armor over wooden and iron hulls. The Gloire and the Warrior. Improvements in armor fastenings. Backing or no backing. The Fairbairn target. The Meteor and the Erebus. The Committee target. Wood-screws *v.* plain bolts. The Warrior target and the Horsfall gun.

III.—*Iron Armor and Smoothbore Guns in the United States.*

The development of the smoothbore in the United States. The Stevens Battery. The New Ironsides. Solid plates and wood-screws *v.* laminated plates and blunt-bolts. The Monitor. The Passaic class and the Charleston forts. The Tennessee and the Atlanta. The 11-inch and the 15-inch guns on the firing-ground. French and Russian experiments with 11-inch steel shot. The 15-inch Rodman at Shoeburyness.

IV.—*Iron Armor and Rifled Guns.*

The development of the rifle in Europe. Powers of the Whitworth, Armstrong, Woolwich, Krupp, French and Parrott rifles. The Committee on Iron. The Glatton turret. Shoeburyness, Gavres and Spezzia. The engagement of the Huascar. Heavy solid plates. The Chalmers target. The Minotaur, Bellerophon, Hercules and Lord Warden targets. Improvements in backing and fastenings. The Inflexible armor disposition.

V.—*Compound and Steel Armor.*

Original suggestions. First trials of steel and homogeneous metal. Wilson and Ellis patents of compound plates. Schneider's steel plates. Whitworth's scale armor. Competitive tests of thin deck plates. Torpedo boat plates. Compound plates and heavy rifles. Competitive tests at Gavres. The Spezzia competition. The Ochta experiments. Palliser's new projectile. Present status of the rival systems.

VI.—*Inclined Armor. Manufacture of Armor. Penetration Formulas.*

First experiments with inclined plates. Deck plates. Monitor decks before Charleston. Curved decks. Late experiments on iron, compound and steel deck plates. First manufacture of plates. Improvements in methods. Compound and steel manufacture. Laws of penetration. Fairbairn, Helie, Noble. The formulas.

PROCEEDINGS

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VOLUME V, No. 1. Whole No. 6. 1878.

VOLUME V, No. 2. Whole No. 7. 1879.

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VOLUME VIII, No. 4. Whole No. 22. 1882.

VOLUME VIII, No. 4—(Continued.)